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OF THE

American Association

OF

Petroleum Geologists

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Chas. H. Taylor, Editor

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of

PETROLEUM GEOLOGISTS

REGULAR PUBLICATIONS

The Association issues annually a publication entitled "Bulletin of the American Association of Petroleum Geologists."

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Description of the Published Volumes.

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OFFICERS FOR 1919

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CHAS. E. DECKER, *Secretary-Treasurer*
Norman, Oklahoma

CHARLES H. TAYLOR, *Editor*
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THE CONSTITUTION

(Adopted in 1918)

Article I.—NAME

This Association shall be called THE AMERICAN* ASSOCIATION OF PETROLEUM GEOLOGISTS.

Article II.—OBJECT

The object of this association shall be the promotion of the science of geology among the men engaged primarily in the geology of petroleum and gas.

Article III.—MEMBERS

Section 1.—Any person actively engaged in the work of the Petroleum Geologist, studying petroleum geology, teaching this subject or related subjects, or connected with a State Geological Survey in the capacity of geologist or assistant geologist is eligible to active membership in the American Association of Petroleum Geologists, providing: that he is a graduate of an institution of collegiate or university standing in which institution or institutions he has done his major work in geology, or, if he shall have carried on studies in such institution or institutions, and shall have published a creditable book on some phase of geology, or an article on some geological subject in some periodical of generally accepted scientific standing, or whose standing in the profession has been favorably passed upon unanimously by the executive council.

Section 2.—Any person having completed as much as twenty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, shall be eligible to associate membership in the

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*At the 1918 annual meeting the name American was substituted for Southwestern.

American Association of Petroleum Geologists, providing that at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing or shall be engaged in geological work.

Section 3.—Active and associate members shall be elected to the association according to the qualifications outlined in sections one and two, providing that the applicant properly fills out the regular application blank, including the signatures of two active members of the association, and that such application be approved by at least three of the members of the executive committee of the association as provided for in Article IV, sections 1 and 4.

Section 4.—Associate members shall enjoy all the privileges offered by the association save that the associate members may not hold any office, sign the application for new members, nor vote on constitutional amendments.

Article IV.—OFFICERS

Section 1.—The officers of the association shall consist of a president, a vice-president, a secretary-treasurer, and an editor-in-chief, who together shall constitute the executive committee of the association.

Section 2.—The officers shall be elected annually from the association at large.

Section 3.—No man shall hold the office of president or vice-president for more than two years in succession.

Section 4.—The executive committee shall consider all nominations for membership and pass on the qualifications of the applicant, shall have the control of the association's work and property, shall determine the manner of publication and pass on all materials presented for publication, and may call special meetings when and where thought advisable and arrange for the affairs of the same.

Article V.—MEETINGS

The annual meetings shall be held at a time most convenient for the majority of the members at a place designated by the executive committee. At this meeting the election of members

shall be announced, the proceedings of the preceding meeting be read, all society business transacted, scientific papers read and discussed, and officers for the ensuing year shall be elected.

Article VI.—AMENDMENTS

The constitution may be amended at any annual meeting of the association by a vote of three-fourths of the active members present at the time voting on the amendment.

Article VII.—PUBLICATION

The proceedings of the Annual Meeting and the papers read shall be published in an annual bulletin. This shall be under the immediate supervision of the Editor-in-Chief, assisted by a Publication Committee, consisting of three members to be appointed by the President.

BY-LAWS

DUES.—The regular dues of an active member of the association shall be five dollars. The yearly dues of an associate member of the association shall be three dollars. These annual dues are to be paid to the secretary-treasurer on or about January first for the year ending the following December.

Any member in arrears for more than two years shall be dropped from the roll of members providing he shall have been informed of his deficiency by the secretary-treasurer, a second time after an interval of six months.

The payment of the yearly dues entitles the member to receive without further charge, one copy of the proceedings of the association for that year.

AMENDMENTS

These by-laws may be amended by the vote of three-fourths of the active members present at any annual meeting.

ACTIVE MEMBERSHIP ROLL

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Applin, Paul L.	Harrison & Eaton, Dallas, Texas.
Armstrong, J. M.	Caribbean Co., Maracaibo, Venezuela, S. A.
Arnold, Ralph	Un'n Oil Bldg.,Los Ang'ls, Cal. & 120 Bdwy, N.Y.
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Beede, J. W.	304 West 38th St., Austin, Texas.
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Belt, Ben C.	Gulf Production Co., Ft. Worth, Texas.
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Bruyere, Alan	The Texas Company, Cisco, Texas.
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Bybee, Hobart P.	University of Texas, Austin, Texas.
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Cumming, C. L. ________ (U. S. Army.)
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Dott, Robert H. --------Empire Gas & Fuel Co., Bartlesville, Okla.
Ford, Carl S.----------1523 West Cherokee St., Enid, Okla.
Frantz, Esther F.-------Roxana Petroleum Co., Arcade Bldg., St. Louis, Mo.

Grove, I. H.------------(Address Unknown.)

Hans, Oscar E.---------Empire Gas & Fuel Co., Bartlesville, Okla.
Hanson, Leslie C.------500 Reynolds Bldg., Ft. Worth, Texas.
Henley, Arthur S.------609 Carter Bldg., Houston, Texas.

Kolm, Robert M.------Empire Gas & Fuel Co., Bartlesville, Okla.

Lowe, H. J.-----------609 Carter Bldg., Houston, Texas.

Mason, Shirley L.------5554 Avondale Place, Pittsburgh, Pa.
Miller, Willard L.------2505 West 10th St., Oklahoma City, Okla.
Morgan, Harold L.† ---Tulsa, Okla., (U. S. Army.)
Moyer, W. Irwin-------3525 Forbes St., Pittsburgh, Pa.
Mulky, Francis P.------(U. S. Army) 201 W. 14 St., Oklahoma City, Okla.

Probst, Fredrica-------Roxana Pet. Co., Arcade Bldg., St. Louis, Mo.
Purdy, Wesley† -------Hotel Jefferson, Dallas, Texas.

Ramsey, R. H.--------(Address Unknown.)
Ross, Sam'l Clarence---U. S. Geol. Survey, Washington, D. C.
Roundy, P. V.---------U. S. Geol. Survey, Washington, D. C.

Scott, Walter W.-------608 Carter Bldg., Houston, Texas.
Stover, Jerry S.-------Lone Star Gas Co., Dallas, Texas.

Witteven, G. W. -------(Address Unknown.)

ACTIVE AND ASSOCIATE MEMBERSHIP ELECT

Ball, Max W.----------Roxana Petroleum Co., Cheyenne, Wyo.
Bradley, Oliver U.*-----410 Federal Bldg., Tulsa, Okla.
Burtt, John Gurney----Roxana Petroleum Co., Mineral Wells, Texas.
Bush, Reed ‡ -----------State Mining Bureau, Taft, Cal.
Greger, D. K.-----------Bartlesville, Okla.
Hughes, Richard ‡ -----Cosden Oil & Gas Co., Tulsa, Okla.
LaNeve, Robert Owen ‡ -Porter-Wertz Oil Syn., Eastland, Texas.
Levorsen, A. Irving ‡ ---Greenwood Co., Finance Bldg., Kansas City, Mo.
Nickell, Clarence O.*---Mar.-Tex. Oil Co., Corpus Christi, Texas.
Owen, Edgar ‡ ---------% John C. Keys, Lawton, Okla.
Pasewalk, Lloyd H.-----Empire Gas & Fuel Co., Bartlesville, Okla.
Whitehead, R. Brooks--Atlantic Oil Producing Co., Dallas, Texas.

*Associate Elect.

†Mail sent to this address was returned.

‡Now active members.

Please notify Charles E. Decker, Sec'y., Norman, Oklahoma, of any mistake, or change of address.

Proceedings *of the* Fourth Annual Meeting *of the* American Association *of* Petroleum Geologists

Held at Dallas, Texas, March 13 to 15, 1919.

The fourth annual meeting of the American Association of Petroleum Geologists was called to order at 10:30 a. m., in the Adolphus Hotel, by President Alexander Deussen.

After an apt introductory statement by the president, Mr. Gilbert H. Irish was introduced, and in behalf of the Dallas Chamber of Commerce and Manufacturers' Association, gave an address of welcome. Short addresses, which follow these proceedings, were then given by Dr. David White, Dr. I. C. White, Dr. J. A. Udden and Dr. W. F. Cummins. The president then called for brief remarks from J. A. Taff, T. B. Gregory, and Lee Hager.

TECHNICAL SESSIONS

At the technical sessions on Thursday afternoon, and Friday and Saturday, excellent papers were given, the titles of which appear in the table of contents of this volume. The officers of the association are to be congratulated upon the importance and value of these papers, and are to be highly commended for their successful efforts in securing for the program men of rich and extensive experience and of high scientific attainments.

PUBLIC SESSION

On Thursday evening, March 13, a popular meeting was held in the auditorium of the Municipal Building. Addresses were

given by Dr. David White, Chief Geologist of the United States Geological Survey; and by Dr. J. A. Udden, whose subject was "Oil-bearing Formations of Texas." Following these, a well illustrated lecture on "China" was given by Mr. Myron L. Fuller.

SOCIAL SESSION

On Friday evening, March 14th, the members of the Association and visitors at the meeting were the guests of the Chamber of Commerce and Manufacturers' Association, at a banquet given in the Junior Ball Room of the Adolphus Hotel. The chief speaker of the evening was Dr. Ralph Arnold, Valuation Expert, United States Treasury Department. His subject, "Valuation of Oil Properties," was presented in a masterly manner. After this address two minute talks were given by David White, E. W. Shaw, Chester Washburne, Judge Greer, J. Edgar Pew and others, the more serious part of the program being interspersed by witty toasts, music and cartoons.

BUSINESS SESSION

March 15th, 4:00 P. M.

The fourth annual business meeting was called to order by President Alexander Deussen, who made a verbal report and gave a number of suggestions concerning the future of the Association. Among the suggestions were these: that great care should be taken in the admission of members; that the present officers pass on all applications for membership made at the Dallas meeting; that the funds of the Association be increased by raising the yearly dues to $10.00, and possibly also by requiring an initiation fee of $15.00 or $20.00; that arrangements be made to pay the secretary-treasurer for his services; and that steps be taken to help differentiate between well-trained, trustworthy geologists and those who simply represent themselves as such.

The report of the secretary-treasurer, W. E. Wrather, was next called for. In view of the fact that the report had not been completed, an approximate statement of the financial condition of the Association was given, this statement giving concrete

evidence of need for great financial resources for the Association. Mr. Wrather recommended that members whose applications were lost be asked to fill out new blanks, to complete the records.

Mr. Thomas, former president of the Association, Dr. Schuchert and Dr. Moore made helpful suggestions concerning the conduct of the business.

Mr. Taylor, the editor, reported that 1000 copies of Volume II had been printed in February, and that copies had been sent to all members where the address was known. He recommended that all manuscripts be sent in not later than two weeks after the annual meeting, and that due care be given to the preparation of the manuscripts for publication.

A motion made by Mr. Bates to the effect that the yearly dues be increased to $10.00 was carried, also one by Dr. Johnson that the fiscal year be made the calendar year, and that the increased dues go into effect January 1st, 1920.

A motion was carried that the Association continue to publish its proceedings in an annual Bulletin under its own name.

Resolutions of appreciation were adopted to Dr. Chas. Schuchert, Mr. Ralph Arnold, Dr. David White and Mr. E. W. Shaw for coming so far and contributing so largely to the success of the meeting, and to the Chamber of Commerce and Manufacturers' Association, and the citizens of Dallas, for their co-operation and fine hospitality.

It was voted that those who shall contribute as much as $200.00 to the Association will become Patron Members, or Life Members.

A motion carried to have a directory of the members prepared for publication and to announce it as available on request.

E. W. Shaw, R. A. Conkling and C. E. Decker were appointed to secure a suitable emblem for the Association.

A motion was unanimously carried that the Association extend its thanks to the outgoing officers for their efficient work.

Officers elected for the ensuing year are: I. C. White, president; Irving Perrine, vice-president; C. E. Decker, secretary-treasurer; and Chas. H. Taylor, editor.

The meeting was declared adjourned.

INTRODUCTORY ADDRESSES

ADDRESS OF WELCOME

By GILBERT H. IRISH, *Dallas, Texas*

Mr. President and Gentlemen:

It gives me a great deal of pleasure, in the name of the Chamber of Commerce and Manufacturers' Association with its 1500 live members, and also in the absence of the Mayor in the name of the City of Dallas, to welcome you here.

The City of Dallas is proud of its record, it is proud of its great buildings, its great financial institutions, its great educational institutions; it is prouder still of the spirit of its business men—the Dallas spirit, the spirit of energy, of youth, which spells progress—and in the name of the City and of the organization I represent, I welcome you.

We recognize that you gentlemen represent one of the great branches of the oil industry. It is up to you to find the oil, and without it having been found all others engaged in the oil industry would have nothing to do. We trust that in your stay in our City you will find convenience and pleasure, and that you may in your deliberations get the benefit of co-operation and exchange of ideas. We trust, too, Mr. President, that on Friday night we may have the pleasure of your attendance at our banquet. We want to make your stay pleasant and profitable to you.

ADDRESS

By DR. DAVID WHITE, *United States Geological Survey, Washington, D. C.*

Mr. President and Members of the Association:

I am experiencing two surprises this morning, one of them very agreeable to me and one of them perhaps disagreeable to you. The first is caused by the great number and enthusiasm of the geologists who are here, the second is the surprise of seeing

the program and finding I have to say something—I have the advantage on that score—but as I look you over I find many in the audience who have been my colleagues and associates—we were working in the same concern, for the same company, if you please, at that time—and there will be more of us after a while, I presume, so that in one respect it is a reunion for me, Mr. President, and I am very greatly pleased to be with you today, you may be sure.

One cannot look over a meeting like this, especially if he has knowledge of its personal composition, ability, responsibility and dynamic force, without appreciating the power and the importance of the body of men who are here seated. The other day, in New York I believe it was, a number of steel magnates working through the Iron and Steel Institute, determined, according to newspaper reports, the prices of steel to prevail for some period, and it was really a very important meeting. I suppose, as viewed by the public; but one may well ask whether the work of the geologists here assembled are doing is not of greater and more vital importance than was the work of the steel men in fixing the price of steel, for it is on your work and on your thought that the world's oil supplies of the future are depending—it is up to you to discover them.

The steel people themselves will put the money in it; the oil magnates will develop the ground if you will discover it, but the actual discovery of the oil in the ground is for you, and that is the important part. Therefore, you see I hold a tremendously high respect for your Association Mr. President, and I take pleasure in bringing you greetings from Director Smith of the Geological Survey, and from my colleagues in the good fellowship of oil and gas.

ADDRESS

By Dr. I. C. White, *State Geological Survey, Morgantown, W. Va.*

Mr. President and Members of the Association:

I bring you greetings from not so large a State as Texas but one that has played a very important part in the oil in-

dustry. West Virginia has an area of only 24,170 square miles—it would take several areas of that kind to fill up the State of Texas—but the petroleum business really began in West Virginia. Those of you who have read the history of petroleum in this country will remember that even as far back as 1826, we had quite a large industry in collecting petroleum from one of those great anticlines which passes through the State of West Virginia, often known as the Burning Springs anticline, which brought the shallow sands, the Cow Run, the Dunkard and the Second Cow Run sands, to the surface and the oil passed out of them into the sands or clay along the alluvial bottoms of the Hughes River, Ritchie County. The very early settlers of that region collected it in the usual manner, with woolen cloths and so forth, and a firm, Bosworth, Wells & Co., whose records we have access to, a merchandising concern, has preserved records of their oil sales at the time, and the price they got for it, thirty-five and forty cents a gallon, away back in the 40's, so that the oil industry really began in the State that I represent.

Then also we invented all the drilling tools. The essential ones were invented in drilling for salt at Charleston, the capitol of West Virginia, so that West Virginia has played a very important part, and as your chairman has referred to your speaker as the "father of oil geology," it is very meet and proper that the State in which the oil industry began, should have furnished the geological clew to the occurrence of oil and gas.

Then also you have deep wells in Texas, but West Virginia has the deepest well in the world. Last year we finally succeeded in beating the Germans not only in the field of battle but in the field of drilling. Our deepest well is 7,386 feet, and another is being drilled by the same company, the Hope Natural Gas Company—one of the companies that the Supreme Court of the United States in its decree of dissolution, permitted the Standard Oil Company of New Jersey to retain. They are now drilling another well, the Lake Well and are down about 7,150 feet, having only about 200 feet lower to go to where the Goff well stopped at 7,386 feet, and it is the wish of Mr. J. B. Corrin, Vice President of the Hope Natural Gas Company, to make the Lake Well in Marion County, West Virginia, still deeper than the Goff boring, in friendly rivalry to Mr. John G. Pew, under

whose management the Goff well was drilled and who is the twin brother of J. Edgar Pew, the accomplished and successful head of the Sun Oil Company of your city, so that West Virginia will most probably soon have two of the deepest wells of the world.

The history of the Goff well was closed by failure to remove the broken steel cable and tools. Some of you may have read my paper on that subject. They could not get the fishing tools into the liner. The well stopped in the Corniferous limestone. The liner didn't come to the surface. There was a cave in the five thousand feet of shale which separated the oil sands from the Corniferous limestone, and the top of that liner had somehow fallen over and when they lost their tools with 2,000 feet of cable in the hole, and sent the fishing tools down, they missed the opening into the liner going along the side of it and hence the case was hopeless. They tried the cementing process and then endeavored to drill into the liner but after working several months they had to give it up.

My friend from Washington of the same name—and I hope we are related somewhere back—has had something to do with testing the temperature of these wells through one of his able lieutenants, Mr. C. E. Van Orstrand. This second well is located on what we call the Chestnut Ridge anticline. I didn't locate it, but one of the Hope Company's force located it, and some curious results have been found there. For instance, Mr. C. E. Van Orstrand, the Physical Geologist of the United States Geological Survey, finds at a depth of 7,000 feet in the Lake Well he has a temperature greater than he had at 7,300 feet in the Goff well, showing that structural features may possibly increase the temperature. In other words, this arching of the rocks, which is probably accentuated at the depth they are, (7,150 feet), may possibly have caused an increase in temperature above the normal for that depth and I hope to be able to secure the consent of the company—in fact, I have that—that Mr. Van Orstrand shall return to the well and make further temperature investigations.

So that West Virginia is doing something for purely technical geology, through the co-operation of these broadminded men, Mr. Bedford, Mr. Teagle, Mr. Sullivan and Mr. Corrin, who are in immediate charge of these great financial interests of the Stand-

ard Oil Company of New Jersey, and one of its vigorous subsidiaries, The Hope Natural Gas Company of West Virginia.

I should say that some of you may be interested in knowing the cost of one of these deep wells. For instance, one that Mr. John G. Pew drilled for the People's Natural Gas Company, (another subsidiary that was permitted to remain with the Standard of New Jersey) the Geary well over in Washington County, Pennsylvania, drilled to a depth of 7,248 feet, cost, I am informed about $112,000.00. That is even more than your Texas wells cost. The Goff well cost only about $47,000.00, but a large amount of both costs was in the fishing jobs and troubles that they met with. The Lake well has not cost nearly so much because they have had practically no fishing to do. So you see that we have wells in West Virginia that cost nearly as much as your Texas wells. I thank you.

ADDRESS

By Dr. J. A. Udden, *Bureau of Economic Geology, State University, Austin, Texas.*

Mr. President and Members of the Association:

I shall not detain you very long. I merely wish to extend to all who are here and all who will come a most sincere and warm welcome to the State of Texas. The State of Texas is the greatest State in the Union areally, and I hope that some day it will be the greatest State in the Union as to both population and wealth. But that is not my greatest hope. My greatest hope is that Texas will lead also in the intellectual world, and it makes us very cheerful to see so many "intellectuals" present here today.

I will say just a few words with regard to what has been done in the past in geology in this State, or rather with regard to what has been neglected. This State has been too busy to concern itself with geology or any other natural history quite as much as some of the Eastern States. This is all quite natural. There have been too great opportunities here for the acquisition of wealth to cause people to look much in any other direction, and I think that this shows a little bit in the development of the

geology in this state. We have been unfortunate in having several geological organizations started and also terminated. In geological work there is nothing of greater importance than continuity of work on the part of those who are in it. I think when a geological organization is reorganized it loses fully as much as one-half of all the work that it has accomplished. In other words, if the same personnel can continue, we know—I am sure each one of us knows—that much is gained. As long as we live, we learn, and this is especially true for the geologists.

Now we lost, first in the disorganization or in the cessation of the old Geological Survey during the war. When the Civil War broke out we had in this State a Geological Survey headed by a competent man, and that was ended in, you might say, a day. I do not think this survey was at work more than about one year. Then Dr. Dumble effected an excellent organization which did some great work, and after a few years that all came to an end. Then followed an interval during which very little was done in geology in this State. Later we had a Mineral Survey that lasted a few years, and that came to an end. So the history of geological work in the State of Texas has not been very encouraging.

The State of New York has issued a number of large volumes on paleontology. Paleontology is almost a new thing in this State. The State of New York has probably done more than any other State for the study of fossils. Ohio has also done much for paleontology in the early days. The Worthen Survey in Illinois issued a very creditable set of papers in the same science. The geologists in those early days were quite advanced in their knowledge not only of formations but also of fossils. Fossils are the chief criteria by which we know the formations. In the State of Texas we have described a great many formations. In that respect I think that perhaps we are nearly abreast with other States. I have no doubt many more formations will be differentiated and described. But our descriptions are lacking in adequate information on the paleontological characteristics of the formations. We have outlined our formations from their physical characters and that is all we have had time to do. We have had very little time to do any of the real scientific work that is so important for the accurate definition of geological units.

No one feels this more than the members of the staff of the Bureau of Economic Geology that I happen to represent.

My wish is that we shall be able to do something better for you gentlemen who are interested in knowing our formations than we are able to do at present. It will be very slow work. If we had known of the demand that there is today for information on fossils, and if we had been at work twenty years preparing for it, I dare say that we would not have had any too much time. As it is, we are really far behind.

I am glad that our Bureau has been able to secure the services of two very competent men, Dr. Beede and Dr. Sellards, and I am sure that with their energies we will be able to do something substantial in the line indicated. And I sincerely trust also, that you gentlemen who are, many of you, working within this state, will do what you can to encourage research work, real research work, not only in paleontology but in every branch of geology.

Again I wish to bid you welcome to the great State of Texas.

ADDRESS

By Dr. W. F. Cummins, *Rio Bravo Oil Co., Houston, Texas.*

Mr. President and Gentlemen:

Probably what I have to say is ancient history. It is a little dangerous, sometimes, to get a man of my age started to talking especially when he feels like it would be impossible in a few minutes to say, or review what ought to be said or reviewed, on such an occasion as this.

If I have any reputation at all, I suppose it results from my work in the Permian of Texas. As early as 1862, when the war was progressing between the North and the South, the Southern Confederacy needed copper to make percussion caps for the use of the army. Dr. DeRay and myself and some others, who had been buffalo hunting up in that country, knew of the copper deposit in Archer County, and we went up there and found quite a lot of copper. We took it to Austin and Dr. DeRay built a furnace and extracted the copper, and they made percussion caps for the use of the Confederate army. Later there was found

some vertebrate fossils in that country. Dr. Jacob Ball worked some time, but unfortunately he died, and Professor Cope employed me to go into that country to collect vertebrate fossils, which I did for a number of years, and while working in that department I found some fossil leaves and plants. We knew of no better man to send them to than Dr. White, of Virginia, and he described my plants. His report was afterwards published in the annual reports of the Texas State Geological Survey. We had a good deal of difficulty in proving that that was Permian. Dr. Charles A. White, formerly the cretaceous man of the United States Geological Survey, came out to see the collection of fossils that I had in this city, and I called his attention to the fact that the Geological Survey of the United States was disputing the fact that the formation there was Permian. I showed him what I had. He said, "Well, did these come from the same horizon?" I said, "Yes, sir." "Well," he said. "with a collection of that kind I can beat the world on your side of the question." I made him up a suite of fossils and he took them to Washington with the understanding that they were to be shown to those men who were denying the fact, and he did so, and they went out saying to Dr. White, "Did you see that place?" "No sir, Mr. Cummins has said they came from there, and his reputation in the country in which he lives for truth and veracity is good enough." He wrote me that. I said, "Doctor, you take your magnifying glass and look at the material that is encrusted on those fossils and you will see a little miscroscopic fellow on each one of them," and I said, "It would be hard to manufacture a collection of that kind with such evidence that it came from the same horizon"; and he did and called the attention of those gentlemen to it. Then they said, "Well, there is no evidence that they came from the same horizon that Professor Cope's fossils came from," and I wrote the same thing and sent them a part of the veretebrate fossils collected from exactly the same place, and it had those little microscopic fellows attached to the material, and when they went in and looked at it they went out, he said, without saying anything, and he reported to me, "Now you have silenced the batteries, look out for the small arms."

I have now and then a young man of some geological attainment who comes into the Permian, or has come into the Per-

mian, and stays three or four days and will go out and say, "Professor Cummins made some mistake about this area." Well, I haven't paid much attention to that, but two or three years ago Professor Orton, who finally succeeded in getting that vertebrate collection of Professor Cope's, said, "You mustn't die until you give us the horizon of those fossils, those vertebrate fossils." There had been no stratigraphic work done in there at all, later I had run some lines across there. He sent me the old original labels that I used of local places that were known at that time and the old letters that I had written to Professor Cope from down in Mexico where I was fighting and eating Mexicans at the time, so I was enabled to give the exact horizon of those fossils that I had collected in the years previous, and that data was published in one of the reports.

So this is ancient history, and that is the history of the Permian up in that country, and the young men have let me alone. Since the horizon of the vertebrates was published, it seems to be beyond their reach.

Now I am delighted to be here this morning and with the privilege of saying this much, and am glad to meet my fellow workers that I have known of and have been knowing for all these years, who have always encouraged me. Professor Cope came out and spent the whole summer in the vertebrate field with me. Dr. White was always ready to describe the flora that we might collect, and he himself has been in the field. Professor Hyatt described the cephalopods, and I am holding some aces now to play against some propositions that are being stated about the Bend. Those of you who know the old-time geologists, such as Dr. Newberry and Professor Hyatt, will probably say that "if they are on your side of the question, why you may be right," but the younger men—I am saying nothing against these men, these younger men, at all, because they are, many of them, doing a very great work, many of them have been at it for some time, and they are zealous, they are good observers, and something will come of their work.

Now I did intend to say that our last fifth annual report, the State Geological Report, was not published, they didn't give us money—that's what is known as the Dumble regime—but I turned over my manuscript to the department, but not having

the fear of man or God before me, when the Commissioner's back was turned to me I picked up that report and lugged it off, and I have that today. I saw Dr. Udden some little while ago, and he said, "Now if you will get that Permian report of yours in shape, that fifth annual report of yours in shape, that Permian report which is of such importance, the Department will publish it," and as soon as Dr. Dumble has time to look over the manuscript and we get it in shape, it will be submitted to Dr. Udden, and I hope some time to see some more of my work in print.

Now, gentlemen, I am very glad to be here and to get this badge pinned on me, with the promise and with the hope of meeting a great many of the geologists that I have not known heretofore. I shall be very happy to meet with you all. I have only a few more years to work, of course, and I like to encourage all the work in Texas that is possible.

I have been down in Mexico for ten years. I have lived over it. I swallowed everything except live Mexicans. When I had to go, why, I beat a quarter nag. Shakespeare says, "He who fights and runs away will live to run—" No, "will live to fight another day." I have changed it: "He who fights or don't fight but runs away will live to run another day."

And I am a standing joke down there about being robbed. They robbed me on all occasions and at all places. They even woke me up at night to come in the room and get what I had, and they always got it. They are the Princes of Searchers for small things. They believe in reciprocity—that is, taking what you have got—but I lived to get out of there, and I can say that I am happy to meet you all, and I hope you will have a pleasant time in Texas and see many things that are of interest.

ADDRESS*

By Dr. David White, *United States Geological Survey, Washington, D. C.*

Having to talk to you tonight is quite unexpected to me, or I would have brought you, of course, the material for a very interesting address. You will pardon me, therefore, if I ramble.

*Address delivered at the banquet.

My theme is that the search for new oil fields is a necessity, rather than a mere duty, and that the search must be carried wherever new fields may be found.

Your oil and gas geologists all know that we are pulling the oil out of the ground at the rate of about 350,000,000 barrels a year, and that in 1918 our consumption was very nearly 400,000,000 barrels, of which about 27,000,000 barrels was drawn out of storage, while we added a net importation of 31,000,000 barrels to meet our needs. Under war conditions drilling has been regulated to a certain extent, wild-catting has been curtailed and with the stimulus of very high prices, we have concentrated drilling in proven territory so that our production has been increased to a maximum. We are now boosting our production curve. With an increase for January of about ten percent over January of last year, and with a December gain of six percent over December of 1917. At the same time, the cessation of hostilities, a certain amount of business stagnation and what might be called a rest period during reconstruction, has resulted in the falling off of our consumption, so that we put a million and a half barrels in round numbers, in storage in January. We will probably put some more in.

Now that quite upsets the estimates as to when we are to pass the peak in production. We are doing our best now. That is reasonably certain; but whether we will go far above 350,000,000 barrels a year in production remains to be seen. Let us hope, of course, that it may be many years before we turn the peak and begin to go down. California has large reserves, and Wyoming and Texas in particular will see great discoveries.

Meanwhile our consumption is bound to rise, in spite of the present slump. It will rise again surely. I leave it to others to predict the rate and the ultimate height. Our civilization, our social and industrial life is based on a prodigal use of petroleum. Extravagance in oil has become a fixed habit, and we are still inventing uses for gasoline and oil fuel.

To return to the subject of production. We are now producing over a third of a billion barrels a year and that is a large amount; for, all together, from the beginning we have produced only about 4,600,000,000 barrels of oil from the ground of the United States. This remarkable increase in both consumption

and production has made oil and gas geologists thoughtful as to our future, and circumstances have several times arisen to prompt the U. S. Geological Survey to prepare estimates of the oil remaining in the ground and available. Geologists all know how estimates like that of the available oil in the ground in the United States are prepared and what they are worth. You know how speculative they are, and how they simply represent the best guess—scientific guess—based with careful judgment and experience upon the best information available. The geologists of the section of Oil and Gas Field Investigations in the Geological Survey have made several estimates, and one made a little over a year ago, and revised somewhat during the current winter to bring it to the first of January, places our remaining available reserve in the ground of the United States at 6,740,000,000 barrels. This total does not far exceed the estimate of February, 1916. It may interest you who live in Texas to know that of these 6,740,000,000 barrels about 400,000,000 barrels is expected to be found in the folded "stratified" and Paleozoic areas of north and central Texas, with a highly speculative estimate of about three-quarters of one billion in the Gulf Coast west of the Mississippi river. North Louisiana ought to produce, if we are not mistaken, about 100,000,000 barrels. We believe that these estimates are conservative. The Mid-Continent Field in which wou also are interested, is expected to yield 1,725,,000,000. These estimates are, of course, subject to revision and will from time to time be revised as further information is gained in the course of exploration and development.

These are large figures and those who are not geologists may think such a large amount of oil in the ground will supply the country for a long time; but such will not be the case. Later the oil cannot be discovered and gotten out of the ground fast enough to meet our soaring consumption. Therefore, in spite of the fact that our production curve is approaching our sonsumption curve at the present amount—or was in January—it is probably only a matter of time, one cannot tell how soon, when again consumption will run away from production, the stores will be drawn upon and our importations will increase to an amount larger than we have yet dreamed of. We used 31,000,000 net importation last year. This quantity is small compared with our

prospective importations in the not distant future. It is to the seriousness of the situation, not necessarily at the present moment, but in the relatively near future, that I wish to draw the attention of oil and gas geologists. To eke out our waning domestic petroleum output, we may use substitutes, such as oil generated by distilling oil shale but such substitutes will not save us from grownig dependence on foreign reserves.

We have been producing for years over sixty percent of the world's supply of petroleum. That sounds quite good to us, and we have been so well satisfied with it that we have become complacent, as though it would always be so. But are we able to do that because we still have sixty percent of the world's reserves in the ground in the United States, or are we in order to produce sixty percent of the world's supply, exhausting our reserves more rapidly than are the other nations and so hastening the day when, instead of dominating the petroleum market, we will be the greatest purchaser or beggar for petroleum in the world? Eventually we shall be mainly dependent on foreign reserves, except in so far as we may alleviate the situation by the use of substitutes for natural oil. This is a certainty. I wish to encourage, I wish to quicken the oil and gas geologists who are here to the discovery of new fields; I would have them urge their companies to take a deeper and broader interest in the acquisition of oil reserves in other parts of the world, and "do it now." The American oil companies would do well to take a larger leaf from the book of foreign companies and assiduously follow the example of the latter in acquiring oil reserves in any part of the earth where oil is likely to be discovered, and that is everywhere; for there is no part of the globe, this side of the poles from which oil will not be brought into use if it can be found there.

The responsibility for finding, first our undiscovered domestic oil fields, rests primarily upon you and upon us. The three states to which at the present moment we are looking for the greatest number of new pools—i.e. for the largest undiscovered reserves are Texas, Oklahoma and Wyoming. California has an enormous amount of oil in the ground, but it remains to be seen whether there are many new districts to be unearthed in that state. Therefore, it is for you, Mr. Oil Geologist, working through yourself,

your companies and your state surveys, to see that our oil deposits are found with skill and with the least waste. When you are wild-catting in fool areas you are wasting, not merely money, investments, equipment, labor and supplies, but you are wasting time and golden opportunities. Above all you will waste opportunity and time and you will sacrifice to an unknown extent the future prosperity of this country if you are not promptly and aggressively active in the acquisition of oil reserves in foreign countries across the ocean—not merely on this side.

It has been said that we are in the "age of iron and oil" and in many quarters the slogan "Iron and Oil" is taking the place of "Iron and Coal." There is much truth is this, without doubt, for on the adequacy of our supplies of petroleum will depend in no small measure, not merely the industrial strength of the country, its foreign trade, and its prosperity, but also the welfare, the comfort, the culture and the everyday standard of living of the American family whether on the farm or in the city. Do not forget this.

PAPERS AND DISCUSSIONS

SUBSURFACE GEOLOGY OF THE OIL DISTRICTS OF NORTH CENTRAL TEXAS.

By JON A. UDDEN, *Ft. Worth, Texas*

In the development of the North Central Texas oil fields there are two terms that have been extensively used, the "Pennsylvanian formation" and the "Bend formation." The first term has been used in many ways. To some the Pennsylvanian implies great possibilities, and the value of a lease is greatly enhanced if it can be shown that it is within the area of the Pennsylvanian formations as indicated on the geologic map of the Bureau of Economic Geology & Technology. Those who are engaged in actual geologic field work are not so enthusiastic, especially when he hears the term Pennsylvanian put to such usage, for his mental picture of the Pennsylvanian is entirely different, it is one that presents many and varied configurations, here and there interrupted, but in places presenting possibilities of values.

The term "Bend formation" or "Black lime formation" has grown in greater popularity and now probably displaces the term "Pennsylvanian formation" in every day conversation among the laymen and technical man. The Bend has been and I believe is still a problem of vital interest to those engaged in geologic studies. At this conference the Bend series will be allowed full swing and perhaps after everything is said we may have new life brought to our assistance in order that we may have some new ideas to encourage us in our work for the coming year.

I shall briefly review "Bend" problems and if possible indicate to you some lines of discussion that may be profitable if we all enter into this meeting in the spirit of helpfulness. No one man is fully conversant as to the whole Bend problem and if therefore it is discussed with the feeling of mutual betterment, I believe the meeting will have been of some value. In the discussions that will follow remember each person has an opinion as to certain problems, respect his opinion and help by giving constructive

instead of destructive criticisms. I believe in the Boy Scouts motto, "Do a good turn daily."

The Bend series is exposed at various points around the older masses of Paleozoic sediments in the Central Mineral Region, principally in Llano, Burnett, San Saba, Lampasas, McCulloch and Mason Counties. It is also to be found in Gillespie and Blanco Counties. The published literature relating to the Bend is limited to the Llano Burnett Folio of the U. S. Geological Survey, and to publications of the Bureau of Economic Geology and Technology.

The Bend series is known to extend to the north, northeast and northwest of the Central Mineral Region. From tests that have been drilled, it is known to occur in Coleman, Brown, Mills, Comanche, Callahan, Eastland, Erath, Hood, Tarrant, Parker, Palo Pinto, Stephens, Young, Wichita, Clay and Denton Counties. It is generally believed to have a greater distribution and from recent developments appears to be present in Runnels and Tom Green Counties. It is generally agreed that very little is known in regard to the Bend series underlying the greater part of the Permian area, likewise it may also be said that very little is known as to the thickness and depth of the Bend in the same area.

The Bend series has been subdivided into three parts, the Smithwick, Marble Falls and the Lower Bend shale. Various estimates have been given regarding the approximate thickness of each of these subdivisions. The Smithwick has been estimated as ranging in thickness from a few feet to a possible maximum thickness of 700 feet, the Marble Falls varying in thickness from 200-400 feet, and the Lower Bend shale from a few feet to 150 feet in thickness. From various estimates that have been suggested as to thickness it would appear that there might be a maximum thickness of 1,250 feet. An expression of opinions along this line would be of interest in giving us a general idea of general conclusions as to maximum and minimum thicknesses. In discussing the present classification of the Bend Series, is there at the present time enough data at hand from either a paleontologic or lithologic standpoint to warrant a further subdivision of the Bend?

There appears to be some uncertainty as to the age of the sediments of the Bend Series. Is there enough evidence at hand

at the present time to discuss the age of the Bend Series? Should the Bend be classed as entirely belonging to sediments of Pennsylvanian age or entirely to Mississippian age? Is it possible that the Bend Series may in part be classed as Pennsylvanian and in part Mississippian, if so where is the line of demarkation. This is a discussion that may be of interest to all of us from a technical point of view, provided those who have had an opportunity to study the paleontologic evidence have had enough material and sufficient time to warrant arriving at some definite conclusions.

It may be of interest to know more definitely the historical period involved during Bend times. What were the conditions under which the sediments were deposited, the condition, extent and abundance of life during Bend times? What was the nature and extent of the deformative movements during Bend times? Again the question may be asked, has sufficient material and evidence been collected and studied to warrant speculation and conclusions as to conditions during Bend times. Further what relations exists between sediments of Bend times to sediments of similar age in either Texas or adjoining states.

It might be profitable to continue our discussion especially in regard to the three subdivisions of the Bend series, along the following lines: Smithwick shale, its extent, thickness and lithologic characters as observed at the outcrop and as developed by drilling. Does the Smithwick show any appreciable thickening or thinning, and if so in what direction? Does it have any lithologic characters that are constant and of value for correlation purposes over any wide and scattered areas. Has any production been developed from the Smithwick shales, and if so what is the containing rock from which production is obtained? Is there any unconformity between the overlying Strawn sediments and the Smithwick, if so, is this unconformity variable, and to what extent, and can any evidence be obtained from sampling cuttings that would help to determine the extent of the unconformity.

The Marble Falls limestone could be discussed in a similar way. An attempt could be made in this discussion to bring out the lithologic or paleontologic differences between the Smithwick and Marble Falls limestone. Does the Marble Falls limestone show any tendency to any thinning or thickening in any particular direction?

What is the character of the petroleum bearing material, is it essentially a free quartz sandstone or is it a limestone, or perhaps an arenaceous limestone? Are these petroleum bearing horizons constant over any large area, or are they erratic and irregular. It has been suggested further that there may be unconformities within the Marble Falls limestone, if so what are the evidences of the same?

The Lower Bend Shale could be discussed similarly and the main lithologic and paleontologic features developed. One might ask what are the predominating sediments in the Smithwick shale Series, how extensive an area do they cover, and do they, as far as we know, exhibit any change in lithologic characters? Further are there any evidences of any unconformities in the Lower Bend shales, has any production been developed from the same and if so what is the nature of the containing material.

Another topic that might be discussed is that of unconformities. Is there an unconformity existing between the Strawn and Smithwick. What is its vertical as well as lateral extent and what criteria can be developed to determine the existence or nonexistence of these unconformities.

The indicated possibilities for discussions up to the present time have been confined more or less to pure geology and may not at first thought have a great deal of economic significance. Problems of more economic importance can be discussed, such as, for example, what subsurface features are most important in the pooling of petroleum. What relation is there, if any, existing between subsurface structures and surface structures. What is the nature of the material from which production is being obtained, is the containing material uniform in texture and extensive over wide areas or are they rather local and irregular in their occurrence? Is the so-called Bend arch as developed by Cheney, Hagar and Hill an actual structural condition or has enough drilling data been developed to produce some more general theories for the accumulations in reservoirs of petroleum. What significance, if any, has the absence or presence of water in the Bend as developed up to the present had with regard to production. What significance can be attached to the presence of large volumes of gas and its effect on production? Why is it an important and essential necessity in order to develop production to shoot a large number of

tests with large quantities of nitro glycerine? What is the probable life of a producing well in this area, and what factors can be used in coming to some conclusion in determining the value of a producing area.

I have no doubt omitted a great number of important problems, that could be discussed to great advantage. Each one of you has some contribution that will be of value and of great help to interpreting the development of the North Central Texas Field. The time is now at hand for a mutual expression of ideas and I trust that all of you will enter into the same to make the time spent here one worth your time while away from your active fields of labor.

I have on the table to my right here some data from the Sinclair, Gulf and Ledbetter No. 1, in Stephens County. It is two or three miles south of Caddo. The well at the present time has probably a production of about eight or nine hundred barrels. The samples that are here and also the thin slides will show you the kind and character of the material from this region. I think it is more or less representative of all the material around Caddo, and also around the Sandage well and the Mid-Kansas Carey No. 1, which is a rather large producer, and I don't know just how to get at it, but we have a number of samples also from other wells, Mr. Eckes has some samples and also Mr. Plummer, and it is awfully hard to show these to you now, but after the more formal part of the meeting is over probably you will be interested in seeing these and then asking questions about them.

DESCRIPTION OF CUTTINGS FROM THE DUFFER WELLS, RANGER FIELD.

By CHARLES R. ECKES, *Houston, Texas*

I have a number of samples here from the Duffer wells. These wells are located about a mile west of the town of Ranger. One thing in particular was noticed in the study of these samples, which most of you are aware of, that is, most drillers when they drill into the Bend formation do not recognize the kind of deposit they are in, but when they get the proper hunch, they call the formation "Black Lime." The record gives so much black shale and lime that no particular horizon can be correlated. Some of us, at first, thought we could determine the sub-surface structures from the well records and prepared structural maps. A little later we began making more careful detailed study of the samples using the microscope and tried to keep a better record. We found that our well records are wrong in many cases—that is, anything that was black and hard was called "Black Lime" by some drillers.

The records of offset wells show that one set of drillers call the formation "black lime" and the same formation in the well across the road from it was called "black shale" by other drillers.

From an anaylsis of these samples we have found that when the drill gets down somewhere near the Bend formation it passes through much black shale, which is probably the Smithwick shale, and then passes through some thin strata of hard black shale containing five to ten per cent of lime with black shale between them. The drill then passes through about a ten foot stratum of pure gray limestone. In our Duffer No. 4 the drill passed through two or three hundred feet of black shale, then passed through a thin stratum of gray lime into sand which produced oil and gas. We are as yet undecided as to what horizon this oil comes from, also we do not know whether this gray lime represents the top of the Marble Falls limestone or whether it is a thin stratum of lime within the Smithwick shales. I think Mr. Udden has experienced the same difficulty in trying to recognize these formations or correlate them in different wells. Those who care to come up and

look at these samples may do so, or ask any questions they wish. I have the samples here to display.

The sand was found beneath the lime, and the samples we have show it to contain fifty or sixty percent lime. So much gas was encountered a little later that the samples blew out and were lost, but from the quantity of gas encountered it is thought to be a good sand with high porosity.

DISCUSSION

Mr. Jones: I would like to know at what depth he found that black shale.

Mr. Eckes: We had shale and lime all the way down, but have never been able to exactly determine where the Smithwick shales commenced, but think it begins about two or three hundred feet above the gray lime which contains oil in the sand just beneath it.

Mr. Fuller: I would like to ask if the production there is what is usually recognized as the Ranger horizon; that is, in that particular well. It usually runs 200 feet below what is commonly called the black lime.

Mr. Eckes: I don't think the top of the black lime exists here. It is shale. The drill simply passed through a thin stratum of lime and found sand and oil; the drill then passed into shale partings and more oil and gas was found below that.

Mr. Fuller: That doesn't answer the question. I was anxious to find out as to whether there was any definite top of the black lime or not. I am inclined to agree with Mr. Eckes. There is certainly an approximate horizon among adjacent wells which is called the Ranger horizon. I am asking if this is approximately the Ranger horizon.

Mr. Eckes: Yes sir, I think it is.

Mr. Taft: In order to get a line on samples, etc., I would like to ask how these samples were taken, and whether or not there are any geologists employed by these companies to inspect these samples and they have some means of educating the drillers so that two drillers on opposite sides of the fence won't call a thing by a different name—one driller on one side of the fence

call it one thing and another driller on the other side of the fence call it another.

Mr. Fuller: I think most of them have experienced samplers on these wells. I can't answer that particular question in regard to these wells; maybe Mr. Eckes can answer that question.

Mr. Eckes: Yes sir, we had a geologist there to collect these samples. I might say we tried to educate the drillers the best we could, but we found out that the best thing to do was to have someone there to collect the samples and get what other information about the formation it was possible to get.

Mr. Pepperberg: I would like to have Mr. Jon A. Udden give a description to those present of some of the slides he has from the Ledbetter well.

Mr. Jon A. Udden: I don't know whether I can do it or not. They have a black lime—anyhow they call it a black lime; but it sometimes depends on how the fellow feels. The material up there, as near as I can see, if you take a sample and look at it, you roughly class it as a shale. Your first impression is that it is probably a shale—at least, that is the impression I have of it—but when you begin to look at it through the microscope and begin to grind a sample down, you begin to see some other things. You begin to see there is a little lime all through the rock, that there is some gray material in it. You begin to see that there are some fossils in it, and you begin to see a lot of string-like things in there, probably, I suppose, spicules of some kind. Now and then you see a little circular structure, suggesting oolites. You see a kernel, and you can see annular rings about it. And I suppose for the upper 100 feet you get material of that character in this well. We are not able to find any evidence of any limestone, or evidence of any sand. I would like to run the slides through and show them to you, if I can have a group of persons around. If you come down to where I have an office I will take some time to show it to you. It is something entirely new; it is hard to describe it.

We didn't have any indication of any sand in the Ledbetter well, that is to say, not a quartz sand. A little oil came in, we had to shoot the well then it came in stronger.

Mr. Deussen: Is there any uniformity as to the producing horizons in these wells?

Mr. Udden: Yes, I think there is, but just how extensive I can't say. I feel that there are certain possibilities along that line. For example, I have developed one thing: I know I have found certain fossils in the formation this last week. I have found fossils, little microscopic fellows, and I have some faith in being able to carry them from point to point. And then there are certain textures of the rocks, especially some of the limestones have characteristic textures, and the so-called black-lime has characteristic textures. It is all a laboratory study.

Mr. Bruyere: May I ask Mr. Udden in what horizon these fossils were that he has discovered?

Mr. Udden: I can't answer that definitely. I understand *you* have found some fossils. Somebody rightly told me you had some, after you had been up at the office, and I never heard anything more about it, and so there you are. We have to help each other on that.

Mr. Bruyere: Mr. Udden, I found one fossil in one well that represented a horizon of Foraminifera, I believe. I never found it in any other well, although I looked very carefully for it.

Mr. Udden: Well, I take it that probably, from the description I got, it was one of those little round Foraminifera.

Mr. Bruyere: I think it was a Foraminifera, but I am not sure about it.

Mr. Udden: I found in the Brown well two fossil-bearing horizons about 100 feet apart, two entirely different forms. One of them looks like an Endothyra Baileyi, if you know what that is. I can't describe it to you. And the other one looks like a Fusulina. And then there is the Ammodiscus.

Mr. Schuchert: When gentlemen talk about fossils it means absolutely nothing. You have got to come down to hard base before you know anything about fossils. The moment you come to Endothyra you have found something. If you have got Endothyra you have probably got Mississippian, but you may have Pennsylvanian.

Mr. Udden: In Illinois there is one Fusulina that is characteristic of the whole state in certain horizons.

Mr. Schuchert: Exactly so. Fusulina ought to be one of the easiest fossils to determine. I cannot understand why petroleum

geologists never get on to Fusulina. It is one of the easiest fossils to learn. If you cut a cross section of the Fusulina in two ways and get to the exact center, you can certainly determine your species, and you can work out your Pennsylvanian horizons. The genus Fusulina begins in the Pennsylvanian and continues into the Permian, and there the species are very different from and far larger than those of the Pennsylvanian. In regard to Endothyra, we may say that it indicates the later Mississippian, but I have a feeling that it also continues into the Pennsylvanian. In regard to Fusulina, however, we know where we are stratigraphically, for this fossil indicates Pennsylvanian time.

GEOLOGIC STRUCTURE AND PRODUCING AREAS IN NORTH TEXAS PETROLEUM FIELDS.

By WALLACE E. PRATT, *Ft. Worth, Texas*

OUTLINE:

Introduction

The subject of this paper is believed to be of interest to many geologists, and it is presented with the idea of initiating and promoting discussion among those interested. The writer does not presume to exhaust the subject, nor even to speak authoritatively on it. His own observations are here set down only as a contribution to the solution of an important and complex problem about which, so far as he is aware, but little is known.

The points to be touched on in this paper are (1) the structure of surface beds, (2) the structure of the sub-surface producing horizons, (3) the relation of surface and sub-surface structure, and (4) the relation of production, both in the Bend and in the overlying sands to surface and sub-surface structure. Closely associated with these subjects is the question of what contribution the geologist has made or can make to the development of the new Texas fields, and this question has been in the mind of the writer in preparing this paper.

The Structure of Surface Beds

Discussion of the structure of surface beds will be confined to an area adjacent to the present important production in Wichita, Stephens, Eastland and Comanche counties. Numerous geologists other than the writer have made plane-table surveys of the important folds in this area. Their maps are remarkably similar in

every case and every statement of fact in this paper is in accord with the results shown on all of them. The term "surface beds" refers to the younger Pennsylvanian and Permian only, no areas covered by Cretaceous rocks or by the Bend Series being included.

The general or regional structure throughout this area is monoclinal, the beds being tilted to the northwest. In the southwestern part of the area the general strike of this monocline is less than thirty degrees east of north, whereas to the north and east the strike is much more nearly east and west. Generally speaking, the monoclinal dip is uniform and is subject to no large modification other than this swing of its strike, as one follows it toward the northeast, from north-northeast to east-northeast.

The most common local deviations from the normal monoclinal structure are of two classes; first, plunging anticlines with axes aligned parallel to the monoclinal dip, and second, terraces with their longest dimensions parallel to the general strike. There are occasional small plunging anticlines with axes extending in directions other than parallel to the general dip, and rarely there are domes, with dips in every direction from a point or short line so as to form a closed structure.

Dips directly opposite to the general monoclinal tilt, however, are unusual and are not persistent, so that domes or closed strucnumbers of irregularly spaced domes, terraces and anticlines that more common east and south of the principal production than elsewhere, and a great deal of interest attaches to the efforts of one of the large companies to develop production on an unusually large dome which lies east of the Ranger field. This fold is elongated from southwest to northeast, or in a direction parallel to the general strike of the beds and the dip to the southeast is locally sharp and conspicuous.

Folds that trend at variance with those of the two general classes, like closed structures, are more common south and east of the present production than they are in the producing area. In the counties most important at present these irregular anticlines and domes are uncommon and small. Nowhere are there the numbers of irregularly spaced domes terraces and anticlines that appear for instance, on the United States Geological Survey maps of some of the Oklahoma fields. The uniform monoclinal structure is strikingly predominant in this area and the only conspicuous

departures from it are the two classes of folds next to be described.

The plunging anticlines that trend in the direction of dip or dip-folds, as they may be called, are marked on contour maps by parallel zones extending across the area at right angles to the strike,in which zones the contours approaching from the southwest detour sharply to the westward to form the south limb of the fold, swing across its axis, and double back eastward again to resume their normal northeastward trend. The plunge of the axis varies from as little as ten to as much as two hundred feet per mile, but very rarely does it reverse itself in the surface rocks so as to develop a domed area of any extent. A fold of this type, persists for a distance more than 15 miles across the general strike of the beds. Generally these folds are not continuous for so great a distance, but folds that die out within short distancts are often found to reassert themselves at intervals farther along the same line of folding. The total fall or dip of the south limbs which, of course, is a measure of the heighth of the fold, is usually not more than 100 feet. Good examples of folds of this type, each one extending across the country parallel with the others, may be seen and mapped accurately in Callahan County near Putnam; in Stephens County at the Parks field, south of Breckenridge; across the southwestern part of Young County; in Wichita County, southeast of Electra; and Wilbarger County, southwest of Electra.

Terrace structure, with the greatest dimension parallel to the strike of the general monocline is the other common type of local structure in this area. In this type not only the spreading of the contours to form the terrace is to be noted, but the presence very commonly of subordinate "noses" or small plunging anticlines that lie on the general terrace. Often these "noses" occur in pairs. Just as the dip-folds can be followed for long distances across the general strike of the beds, so the terrace structures persist for miles parallel to the strike, either continuously or recurringly along the same contours. Good examples of terrace structures may be seen and mapped accurately at Ranger, in western Stephens County, and in southern Young County.

In the nature of things, structure of the two main types just described, being extended at right angles to each other, must intersect and cross. Such intersections have been mapped and the

result, as would be expected, is rather complicated local warpings of the beds.

The Sub-Surface Structure

Concerning the sub-surface structure very little can be asserted with confidence. The general structure, as practically every observer realizes, is far from conformable with the simple monocline in the surface beds. That the Bend Series is arched as a result of its position on the flanks of Llano-Burnett uplift is generally admitted, but that this uplift controls absolutely the general structure as far north as the present productive fields, is questionable. Certainly the various minor arches that radiate away to the northeast around the border of the uplift cannot be depended upon to persist to the producing areas in the manner in which they are projected on various published maps. Neither the position of the crest, nor the plunge of the axis, nor the rate of dip on either limb of the main arch in the Bend Series, can be predicted with security over much of the still critical area.

If the regional sub-surface structure is undetermined the details of the sub-surface structure are still clearly visualized. Probably the Bend Series is more acutely folded than are the surface beds—a suggestion lborne out not only by theoretical consideration, but by the results of drilling. Steeper dip, persistent over greater distances, and greater and more frequent reverse dips in the Bend as compared with the surface beds, seem to be shown by a study of well logs.

The Relation of Surface to Sub-Surface Structure

The relation of surface folds to buried folds cannot be pictured very accurately. Folds in the surface beds in many cases seem to reflect more acute folding in the Bend Series, although there are apparent folds in the surface beds which probably have no counterpart in the subsurface beds. As has been said the folds in the surface beds are less pronounced than the corresponding folds in the Bend. Areas of flat-lying beds or of slight westward dip, are underlain at a depth of 3,000 feet by eastward dipping limestones. South dips of one hundred feet at the surface overlie south dips of two hundred feet in the Bend. Terraces and plunging anticlines—both open to the east—are found above closed structures in the buried rocks. The position of a fold in the

surface beds is often not vertically above the corresponding buried fold. The flat area of a surface terrace may be considerably removed laterally—often in an up-dip direction—from the crest of the fold in the buried rocks. These observations record the essential known relationship of surface and sub-surface structure.

The Relation of Production to Surface Structure

From what has been said it will appear that to attempt to establish a definite relationship between production from the Bend Series and surface structure is a hazardous undertaking. A pioneer operator in these fields facetiously advises that one should map the favorable surface structure and then go elsewhere to drill. A geologist has said that one finds favorable surface structure and then begins to "wild cat" on and in the vicinity of his favorable (at the surface) area.

So far as production from the shallow sands, that is, from sands in the Permian beds in the Cisco, Canyon and Strawn divisions of the Pennsylvanian is concerned, the relation of production to surface structure theoretically would be definite enough; the sands are invariably salt-water bearing, and any oil and gas in them would accumulate in accord with the well-known laws for accumulation under these conditions. As a matter of fact, however, accumulations in the shallow sands have generally proven small and erratic. But then the structure of the surface beds is rarely favorable enough to justify the expectation of large production in sands conformable with them, and even if surface structure were large and pronounced the great irregularity in the lithology and lateral extent of these shallow sands would still prevent perfect response of accumulation to structure. In some instances irregularities in the contour of the roof of the sand reservoir seem to have been important in connection with shallow accumulations.

Production from the Bend Series obviously cannot be directly controlled by the structure of the surface beds, because it comes from sands which are not of the same structure as the surface beds. If one analyses the production from the Bend with relation to surface structure it immediately becomes evident that surface structure does not control exactly. Indeed, surface structure very rarely is adequate to accumulate and retain petroleum

beneath it. Perhaps the relation of both shallow and deep production will be clearer if the structure of each of the areas productive at present be described briefly.

In the Electra-Burkburnett pool in Wichita County the structure seems to be similar to strike terraces described above; the strike of the monocline in this region being only a little north of east. The production is largely on the north edge of the general terrace. Evidence of east dip at the surface is practically nil, and south dips are noted only at Electra—several miles south of production. At Petrolia where gas and some oil is produced the structure is genarally described as dome-shaped.

Of the other shallow fields in this region, all of which are small, Moran is erratically associated with a small terrace; and Strawn has developed on small plunging folds. The unimportant shallow production in Coleman County cannot be related very definitely to surface folds. The surface structure around the shallow sand production in Archer County cannot be determined. The few shallow-sand producers in Stephens and Eastland Counties are generally associated with slightly favorable structural features at the surface. Finally, the shallow wells at Brownwood seem to be on a terrace.

The wells in Young County which have recently shown a promising quantity of oil in the Bend Series is on surface structure of the plunging dip-fold type.

The deep production at the Parks field in Stephens County is likewise associated with a prominent fold plunging with the dip, but the best wells are far down from the crest of this surface fold. The best production comes from the highest parts of the Bend Series, however. In the large surface syncline, south of and parallel to the Parks fold there are four deep tests, all of which are failures. The logs show these dry wells to be extremely low on the Bend horizon as well as on surface structure.

The production at Ranger is associated with a large strike terrace with the usual super-imposed "noses." The best wells are on the down dip edge of the terrace, however, farther than one would have predicted in advance of drilling. On the Bend horizons, on the other hand, the best production is relatively high, as in the case of the Parks field. Up the dip from the terrace at Ranger the tests are uniformly dry.

The production south and west of Caddo in eastern Stephens County is associated with pronounced folding at the surface, but is not confined to the theoretically most favorable parts of the surface folds; that is to say, small sharp synclines that are a part of the larger plunging anticlines (dip fold) are productive.

At the Duke field in Comanche County, the surface structure is obscured by lack of exposures. Since the original location was purely a geological location, however, and was made as a result of much work, it may be assumed that favorable structure exists there in the surface beds.

The two deep wells at Putnam, results from which are encouraging, are on the eastern end of a prominent westward or down-dip plunging anticline.

Wild cat wells at Sipe Springs in western Comanche County and at Byrd's store in northern Brown County have recently made promising showings. The Sipe Springs well is on a westward plunging anticline and the Brown County Well is said to be on an anticline which is elongated from north to south.

The small production so far obtained from the Bend in Coleman County comes from an area in which there is some folding, but is not directly associated with favorable structures.

The Relation of Production to Sub-Surface Structure

Subsurface structure undoubtedly is capable of more control over accumulation than is surface structure. Water, oil and gas occur in the Bend Series exactly in the theoretical relationship to structure so far as continuity and uniformity of reservoir beds permit. The unquestionably more pronounced character of the folds in the Bend suggests this situation at once, and drilling experience does much to verify it. Beneath all the areas of production from the Bend rocks, the producing horizons have been comparatively high and the individual production of wells has been clearly related to the elevation of the Bend horizon in that well. As the Bend rocks rise in any direction, development in that direction is successful, and as they fall development fails and ceases. The validity of this contention is best established by the results of drilling at the Parks pool in Stephens County where the relationship as described is very clear.

The Geologists Contribution to the Present Development

Petrolia, Electra and Burkburnett were discovered by accident, and even in their development geology has not been prominent because of the lack of surface control. Moran and Strawn, likewise came into production without geological assistance, although the geologists followed and mapped the small structures with which the production at each place is associated. Moran proved to be a disappointment, and the geologist was dubious when, following the decline at Moran, it was proposed to drill a wild-cat test in Stephens County, where he found the structure but little better than at Moran. Yet this well was the first commercial producer in Stephens County. Still later the discovery well at Ranger, drilled without geological advice, was not considered important except by the few geologists then in this field who realized the condition which the Parks well in Stephens County had revealed.

If the initial commercial production in this field is not due solely to the geologist, no fault lies with the principles of petroleum geology. His interpretation of observations on the surface beds was logical enough; there was no large favorable structure and consequently there could be no accumulation. This is true enough for the beds conformable with surface beds. His conclusion led him into error because, as is so often the case, sufficient data were not at hand to permit him to know all the geological facts. He could not be expected to attribute the proper significance as we now know it, to the situation that one hundred miles to the south of the region most often under examination was the outcrop of the Bend Series, more highly folded, thoroughly impregnated with organic matter, and underlying unconformably the beds which he mapped.

When oil was obtained in the first deep Stephens County wells, however, the geologist at once realized the significance of the find and diagnosed correctly a situation that has since become patent to everyone. And following the discovery of the first petroleum in deep wells, geologists here have been able to contribute largely to development and even to discover new pools. The future contribution of the petroleum geologist will be increasingly important and extensive as more accurate information is obtained.

The problems of geology in North Central Texas today are research problems, and a geological department in the petroleum industry today should be on the same basis as are research departments in other large progressive industries. Important among numerous other problems which are involved in the geological research are those with which this paper has been concerned; namely, the structure of surface beds; the structure of sub-surface beds; the relation of surface and sub-surface structure; and the relation of production to both of these. These problems particularly must receive the geologist's study as development progresses; the final word on any one of them cannot be said until much more accurate data is at hand, but in the solution of these problems is the greatest future contribution which petroleum geology can make to the industry in North Central Texas.

Summary

The structure of the surface beds in North Central Texas, in so far as it varies from the normal northwestward dipping monocline, is generally of one or the other of two types, first, plunging anticlines which trend roughly in the direction of the maximum dip of the general monocline and, second, terrace-like structures which are elongated parallel to the strike of the general monocline. Both of these types are strikingly persistent, continuously, or at intervals in the direction of their axes or trends. Although important exceptions are known, neither type ordinarily has much closure on the end or side away from the general monoclinal dip; that is, dip directly reverse to the normal is not common nor extensive. Sharp folding is not common at the surface in the producing area and even the gentle folds are distinctively subordinate to the general monoclinal structure.

The structure of the unconformable sub-surface producing horizons is not clearly nor definitely determined. The general structure is obviously not that of the surface beds; that is, it is not a simple northwestward-dipping monocline. The regional structure is in some degree determined by the uplift in the Llano-Burnett area on the south, but probably this control is lost or modified greatly in the distance between the uplift and the producing fields. The local structure in the older unconformable series is more pronounced than the surface structure. Reverse dips

more common and dip angles are steeper. The structure of the surface beds of Pennsylvanian and Permian age is frequently a faint reflection of the structure in the unconformable buried series. The surface folds are less severe, their form is different and their position may not be vertically above the position of the sub-surface fold which they reflect.

Production from the shallow sands—those conformable with the surface—is relatively unimportant, except in Wichita County where surface structure cannot be certainly determined. Structural conditions undoubtedly control accumulation in the shallow sands so far as lenticularity, lithology, etc., permit, but rarely is surface structure large enough and pronounced enough to affect any accumulation. It is significant that so little production has developed in the shallow sands in the new fields in spite of the great number of holes drilled through these sands.

The accumulations of petroleum in the deep lying horizons that are not conformable with the surface are probably controlled by the structure of the enclosing beds in strict accordance with the established geological laws for the behavior of oil, gas and water in a sealed porous medium, except only as erratic sand distribution interferes with such accumulation. With the producing horizon a limestone, however, so that the reservoir rocks are in some cases not sands but porous or cavernous limestones, the non-uniformity of the reservoir rocks modifies normal accumulation greatly. The relation of the accumulations in the underlying unconformable beds to folds in the surface rocks is less precise because of the intervening plane of unconformity. The developed production is strikingly associated with areas of surface folding. It does not come invariably, nor even generally, from the tops of surface folds; it is often low on the flanks of such folds and may even come from local synclines.

Nowhere has important production been obtained on the normal regional monocline in the absence of local surface folding nor in large synclines at the surface.

The petroleum geologist has contributed much to the effort to develop petroleum in North Central Texas, and his future contribution will be still greater, but he is not responsible for the initial production from the new fields; a circumstance which is due largely to the facts that he recognized and condemned the sur-

face structures in themselves as inadequate both in size and shape for retaining accumulations of petroleum, and that information as to the underlying unconformable series which now produces the oil was too meager to permit him to predict the situation which has now developed.

DISCUSSION OF PRECEEDING PAPERS

Mr. R. T. Hill: I have been very much interested in Mr. Pratt's paper. However, he makes one or two points to which I wish to take exception. First, concerning the non-presence of the so-called arch, which was mapped originally, I believe, by Mr. Cheney, later by Mr. Hager, and later published under my name, for which I disclaimed all responsibility. Apparantly Mr. Pratt's examples have been taken from Stephens or Eastland County, where this so-called arch has apparently flattened out and lost its individuality, but my observations have been largely confined to the southern end, in Brown and Comanche Counties, along the outcrop. I think it is absolutely demonstrated mathematically with some cross sections we have in Brown and Coleman Counties, that that arch does extend as a sort of nose from the outcrop to the northern edge of Brown County, where we have recently discovered some little oil almost on its apex.

The second point on which I might differ with him is in the fact that the structures in the Bend are not reflected at the surface. Through Brown County we have a perfect series of logs on the apex of this arch from the southwest corner of Brown County and McCullough County northeastward toward Comanche to the north edge of Brown County, and the wells drilled are some on structure and some not on structure, and the only wells in Brown County drilled on structure have either shown oil or a suggestion of oil, while the well south of Bangs drilled by Mr. L. B. Carter of Pennsylvania and his associates, shows ten or twelve million feet of gas at the top of the Bend Series. Now, this well was drilled on structure previously determined and mapped out by Mr. Hager, and today it is one of the best structures in Brown County. About fifteen miles north of this locality, in the direction of about north 20 degrees east, two or three other

structures were developed and we have again recently found oil in those structures which appear almost on the summit of this Great Arch. First, a good showing of oil, some thirty or forty barrels, was found two or three miles west of the apex of that structure, in what is known as the Bayley well. The Sinclair well, which came in some two weeks ago, was located, in my judgment, at the apex of this structure, and although I am not in possession of the definite figures, which perhaps Mr. McKee of the Sinclair Company will know, from the datum given, this well is fifteen feet higher on that structure and gives a proportionate amount of oil.

Now we have a cross section of that structure running about twelve miles south of east giving these wells. Maps were made to show all of the data of these wells, and they show perfect symmetry. The Bartles & Dumenil well, some six miles to the southeast, finds similar horizons, in my judgment, although the gentleman with the microscope may somewhat differ with me—it finds similar horizons some 300 feet lower on that arch. And the Grosvenor well, somewhere to the northwest, finds similar horizons also some 300 feet blow.

I would be glad to show you any of these today in my office, in the American Exchange Building, if any of you should be interested in them.

Now I do not state these things in criticism of Mr. Pratt's paper, for I think it is most valuable and instructive, but I do have some faith in the reflection of the Bend structures on the surface, and I think we have had some magnificent, I would say, and contributory evidence as to the value of the geologist in locating these structures. I think there are no greater or more perfect illustrations of this in all the history of the oil business than Mr. Wrather's determination of structure in the Duke locality, and there are several other instances which I could give.

I will conclude by simply saying that in Brown County absolutely the only showings we have of deep oil have been on the apex of this structure and in other structures, and there have been many failures where the structures indicated nothing and where the people said "blank the geologists."

Mr. Pratt: I think Dr. Hill may have misunderstood me. I didn't mean to say what he attributes to me. I believe that many very slight surface structures are reflections of more acute struc-

ture in the Bend, and if I led Dr. Hill to believe that I had no faith in surface structure I am sorry, because I do have faith in the significance of surface structure. We are mapping surface structure, but we are trying to interpret it a little bit differently than we did two years ago.

For instance, Dr. Hill has just stated the conditions in northwest Brown County where the initial well for that region, a rank wild-cat but carefully located on top of favorable structure in surface beds, has just come in, a small producing well and the first real producer in Brown County. Now Dr. Hill's statement describes accurately the situation which existed in Stephens County two years ago. The geologists had gone on to the Parks ranch, miles from any production, a first well had been drilled on a site selected by them, on top of a favorable structure, and had been completed a 75-barrel well. The geologists were elated, just as Dr. Hill very properly is over the present situation in Brown County. But look at the situation in the Parks field in Stephens County today, two years subsequent to its discovery. On top of the favorable structure are the original well; a few small wells and two dry holes, while two or three miles to the northwest, so far down on the flank of the anticline as to be practically off of it entirely, are a half dozen large wells, ranging up to 3,000 barrels initial capacity. Actually, then, the best site for the first test at Parks was not on top of the structure, as it appeared at the surface, at all. Perhaps after two years of further development, northwest Brown County will appear in a different light.

This situation is in my mind when I state that we now interpret our surface features differently than we did formerly. We recognize unconformable relations between surface and producing horizons and take into account the probable effects of that unconformity.

So far as the persistence to the north of the Bend Arch is concerned it is not my idea to deny the presence of this arch in Eastland and Stephens Counties. This arch was first shown on a map made and published by Mr. M. G. Cheney and in the same form later by Mr. Dorsey Hager. These maps were published more than a year ago when data on which to place contours were few. Naturally the maps are not accurate. Yet many people today seem to visualize the arch just as it is shown on these maps,

and it is to this definite conception of the arch that I object. The arch may exist, and may be present beneath Stephens County, but its form, the position and trend of its crest, and the rate of dip on its flanks are not known accurately as far north as Stephens County, and are not what the old maps portray them to be in Eastland County. Probably these features of the alleged arch in Eastland and Stephens Counties were no longer controlled exclusively by the Llano-Burnett up-lift as they may have been in Brown County.

I think there is no serious disagreement between Dr. Hill and myself.

Mr. Schuchert: I would like to ask the gentlemen present whether they are paying strict attention to the different movements that have taken place at different times. The latest movement of the earth's crust must have affected all the formations beneath at the same time, but how many movements were there before this latest one? There certainly was a time of mountain making in Texas before or after Bend time, and there certainly was another movement during the Pennsylvanian, probably not so strong here as away off in the Southwest. There appears to have been a third time of deformation at the end of the Permian, and finally a fourth one at the close of the Cretaceous. All of these movements must be considered, because they have produced a subsurface structure that is not reflected at the surface.

Mr. Fuller: Mr. President, I think Dr. Schuchert has put that exactly in the right light. While a Bend structure is not necessarily reflected at the surface, the surface structure is necessarily reflected in the Bend, for the reason that any movement which warps the surface formation must also necessarily produce a warping in the Bend. I agree with Mr. Pratt as to the breadth of the arch, although I think, perhaps, it is a little more pronounced and a little more definite than he has stated. I agree that it flattens out in the northern counties, especially on its western side. On the east, as far as my records show, the dips are more pronounced than to the west, carrying the Bend down into what I believe is a deep syncline in Clay, Jack, and Palo Pinto Counties.

Now in regard to the matter of the doming, he has stated that it seems to be most apparent in the southern part of the field

and is not so much in evidence in the middle part. I agree with that most heartily. Going further north, however, my observations seem to indicate that doming begins again in Young and Archer counties and is conspicuous there. Of course I realize that such a statement is open to question because of the character of the rocks, especially the prevalence of sandstones, which are not good beds to work on, but it seems to me that a competent geologist can work out the structure in most of that region, not with the accuracy one can do it in the Ranger field, but it may be worked out in its broader, general features. My observations there show that doming begins to become more pronounced north of the central part of Young County, and continues we will say, into northern Archer County. In other words, it is limited to a sort of a synclinal depression, though not a definite syncline, between the definite Electra-Burkburnett arch on the north, and the normal northwest dips on the southeast.

Now as to the Morris wells—for although he did not mention names but referred only to the production of the southern wells, I assume he referred to the Morris group—it should be borne in mind that there are two distinct structures to be considered, an anticlinal surface structure and a regional syncline. The latter, which is not a sharp synclinal trough but a broad regional synclinal bowing or swing, will undoubtedly be a very important factor in controlling the production in the Morris district.

Mr. Cummins: I should like to ask these gentlemen that have been talking about the Great Arch, if we are to understand that there is but one arch in the Bend Series. You all know that I put the Bend in that geology up there. As I traced that Bend from where I first saw it in Lampasas County to the westward, I found that bed dipping at several angles in different directions, and I have been of the opinion that there would prove to be more than one of those Arches extending through the country. Now I don't know whether I understand the gentlemen to give us to understand that there is but one of those folds extending through the country. I would like to just ask that question, if they consider that there are more than one of those Great Arches of which they have been speaking.

Mr. Deussen: I think, Dr. Cummins, the interpretation is

according to the map of Mr. Cheney's referred to, which I believe would make only one Arch. Isn't that right, Mr. Pratt?

Mr. Pratt: One regional arch.

Mr. R. T. Hill: Dr. Drake's sections did show several folds, and I think theoretically oil men are working on the line that there may be other arches east of this main Arch, of which we are talking, and they are drilling trying to find such arch now in Hamilton and those counties to the east. It is suspicioned that one of those arches runs through Comanche County, and there are two or three wells now being drilled, but it is this arch to which most attention has been given and in which most development has been made.

Mr. Beal: I would like to ask if Dr. Hill considers the accumulation of oil due to this regional arch, and if he would condemn territory that shows an original syncline. Is there a possibility that an accumulation may be due to small structures superimposed on the main structures, and that the original structures may not have so much influence on the position of the accumulation of oil?

Mr. Hill: Mr. Chairman, I fear I cannot, not having given sufficient reflection to the question, but I do know the wells in the eastern dip of this arch in southern Comanche County, San Saba, Mills and in the eastern portion of Brown County are dry—not literally dry but in cases giving artesian water—and are free from oil and we can now map out a large territory in the synclinal slope of this arch in parts of Brown County in which I would advise no man to spend money in sinking a well.

Mr. Pepperberg: In the absence of Mr. Cheney, who is overseas at the present time, I think I can say a word about his map which may be of interest. He brought it to my attention in October, 1917, and at that time he gave Dr. Cummings all credit due him for the dips which Cheney had shown around the Llano-Uplifts. At the same time Mr. Cheney informed me he had gone over this matter with Mr. William Kennedy, who I think gave him some very valuable suggestions. Cheney's article entitled "The Economic Importance of The Bend Series As a Source of Petroleum Supply," was published in the April number of the Oil Trade Journal, and the map which should have accompanied this article appeared in the May number of the Jour-

nal. This map is dated December 17, 1917. I came to Texas about October 16th, 1917, and at that time Cheney had his map pretty well worked up. His map covered approximately 25 counties. The contours were based on a very few scattered well logs, some of which were from 20 to 50 miles apart. His map was intended to give only a general idea of the large regional structure. Since that time I have followed his idea to some extent myself, and I am of the opinion there is an uplift—I think Mr. Fuller, is of the same opinion—which extends from the Llano Uplift to the Wichita-Arbuckle Uplift and passes through the various counties where we now have production. Also we have some indications of another regional anticlinal arch which connects the Llano Uplift with the Arbuckle Mountains by way of Coryell, Hill, Johnson, Tarrant, Denton and Cooke counties. This latter anticline is hypothetical but if it exists; and there is some good evidence for the assumption that it does; there must be a large regional syncline between the two arches which connect the Llano and Wichita-Arbuckle Uplifts.

From a series of well logs which we have to work with, I find to my own satisfaction—and I suppose a great many here will differ with me—that at least one if not two, of the larger producing areas between the Oklahoma line and the Llano-Burnett Uplifts are more or less roughly parallel to the trend of these uplifts. Take the Stephens County productive area, especially that region between Breckenridge and Caddo. The Bend oil zone in this district shows approximately 100 feet of south dip and the strike of the subsurface fold is almost east-west. In Eastland County, where the surface structure is weak we find a fairly well developed subsurface structure. The 1600 feet below sea level contour in the north west part of the Ranger field has an east-west strike, which I think crosses to the western part of the county, swings south through the eastern part of Callahan County, then east to northeast into the southwest corner of Eastland and then southwest to west out of the southwest corner of the county, making a rather broad structural terrace which has an almost east-west trend. Recently a well is making some oil near the west end of this large structure and while this well is not completed it serves as a pointer. I confidently believe production

are worth while will be developed on the minor folds on the broad structure between Ranger and Putnam.

It is my opinion from a study of all the logs I can get my hands on and I am still minus about 150 of them, that the productive areas will not all be east-west structures. Some local structures may be almost round or elongated in various directions. I believe, however, that a grouping of the adjacent productive areas will show that the larger structures upon which the smaller ones are superimposed are roughly parallel to the trend of the Llano and Wichita-Arbuckle Uplifts.

I believe that the surface structures are reflected in the subsurface structure in this region, but more intensely than indicated by the surface outcrops. This is well illustrated by the Sun Company wells on the Allen Ranch where drilling has demonstrated the subsurface dips to be much more intense than the surface indicates.

Going back to the Bend Arch, I think if we can find our line or zone along the theoretical line Mr. Cheney first pointed out, we will have a better chance of obtaining oil than if we drill for it in the northeastern part of Jack County. This district is occupied by the regional syncline which is about 60 miles long, 15 miles wide and 500 feet deep. Near the south end of this syncline there are a few wells which produce some gas and a small amount of very high gravity oil. I do not believe a broad flat zone, such as suggested for the bottom of this regional syncline, would necessarily mean the absence of oil or gas pools, providing local anticlines were found in this basin which were sufficiently well developed to govern accumulation. In connection with this particular region I hope to hear some discussion at this meeting about the "Carbon Ratio," and will be glad to hear it very fully discussed, because I have some ideas about this theory myself.

Mr. Hughes: I will ask the gentlemen responsible for the Arch just how reliable their data are. I think it is mostly based on well logs. That is my notion, after sampling sections from top to bottom and reading the government reports. I would like to know just what you base this large Arch on. There are a number of geologists who are doing sub-surface work at present that don't believe in an arch.

Mr. Plummer: I do not wish to appear as a disbeliever in the Bend arch theory. However, I wish to call attention to the ease with which one can misinterpret well logs. It is not safe to correlate limestones for long distances even from samples. Many limestones that appear in the upper part of the Bend section play out to the east; and again, a hard shaly or concretionary layer may be recorded as lime in one well that is not present in the next nearest hole.

Roxana Petroleum Company, as you know, drilled a hole near Graford, a town located on the eastern edge of the north Texas oil district. In this we found the Bend black shale at a depth of 3,190 or 2,184 feet below sea level, higher than it should be according to the theory for a large eastern dip of the Bend. However, in this same hole the first black Bend lime was found at 3,850, or 2,764 feet below sea level, an elevation that allows considerable east dip if this is correlated with the highest black lime in the Caddo wells. I am quite sure the black shale encountered at Graford belongs to the Bend, as it has all the brittle hard Bend characteristics and the Bend fossils. By careful search we were able to find a number of small fossils and fossil fragments in the samples. In fact a fairly good collection was obtained between the depths 3,350 to 3,450 feet or 2,664 feet below sea level. On the other hand in drilling our test at South Bend in Young County about 30 miles west of the Graford test a similar collection of fossils was obtained at 3,958 or 2,831 feet below sea level. In the South Bend well, however, the top of the black shale was at 3,360 feet (2,,233 feet below sea level) and the first black lime at 3,540 (2,213 feet below sea level). Hence although the limestones in these two wells appear to be dipping east, the top of the Bend shale and the fossil horizon slopes westward.

If the old shore line was along the old Appalachian area, as I suppose, the limestone would naturally play out to the westward and give place to shales. This is what we seem to find in our well logs. The shale has increased from 200 feet in the Caddo field and at South Bend to 700 or 800 feet at Graford and Mineral Wells where the limes have played out and the sands have come in. It is a mistake that can easily be made from a simple study of well logs alone to correlate the first heavy lime

encountered in the Bend series at Caddo with the first lime encountered in the Bend in wells near Mineral Wells.

Now there is undoubtedly some eastward dip of the Bend beds, but I do not think it safe to establish this simply by correlating limestones in well logs or from samples from wells drilled far apart.

Mr. Deussen: I will ask Mr. Hughes to give us his ideas of the eastern dip of the Bend in Palo Pinto County and a brief description of the cuttings from the Holcombe well, Cosden Co., in Eastland County.

Mr. Hughes: Regarding the eastern dip of the Bend, I have nothing definite to state. In collecting the samples from the Holcombe well, I found the same trouble that Mr. Eckes has just described, in checking a drillers report against the cuttings. What they usually get as a great thickness of black lime is a black calcareous shale running about five or ten percent lime. The top of the black lime so-called, is a gray lime, and the great thickness of reported black lime, in the section below this is for the most part a calcareous shale. The particular thing that I noticed in the whole section of this well was that the only real black lime that they got, which carried probably seventy-five to eighty percent lime they list as a black shale. It makes it rather difficult therefore, to correlate such a section over a country comprising several counties, without samples. There are one or two members of black shale, I should say, in the Bend which, if they drill deep enough are reliable for correlation. The lower Bend shale is the one in particular. As a general thing, however, they don't go deep enough to get this shale, and in that way catch only the other formations, black lime or what they call the black lime at the top of the section. The only real markers in the lime section, that we noticed in the cuttings were the gray limes.

The discussion on paleontology as applied to samples, a few minutes ago brought up an idea on that. Mr. Udden, Mr. Pratt and I were doing a little work on my samples of the Holcombe, and those of the Ledbetter test of Stephens County in order to determine the depth to the Ellenberger in a drilling well. I don't know what the fossil was that we found in the sample, Dr. Schuchert has just said that these fossils cover a couple of hundred feet of section, but by means of it we are able to place the Ellen-

berger within, I think, about fifty feet. The fossil was in one of the gray limes of the black lime section. There is nothing in the black lime section that I have seen which can be correlated from one field to another by just using lithologic characters. I have gotten cuttings out of wells from different horizons and so far have had poor luck with it. I have a complete section in the Ranger field from the top of the Marble Falls to the Ellenberger which does not check the driller's report and convinces me, regarding the east dip in the Bend arch, that most of the data for this was obtained from the driller's record. They may have had better luck than some of us have had in the interpretation of the logs.

Mr. Deussen: Mr. Hughes, where did you obtain this fossil? was it from the Ellenberger?

Mr. Hughes: No, that was up about 150 feet. I think it was in the first gray lime.

Mr. Pratt: With reference to this Bend Arch and the east dip, there is one horizon, which, while it is unconformable with the Bend, forms a good key bed on which to contour the regional structure. I refer to the top of the Ellenberger which Mr. Hughes just mentioned, a very definite horizon, which incidentally, can be proven to show at least some east dip on the eastern flank of the alleged Bend Arch.

Mr. Schuchert: Mr. Chairman, I would like to ask another question—I may be getting myself into trouble, but I am here for that. Down in San Saba,—I don't know your geography very well—but then in your lower country your Bend rests on the Ellenberger; as you come north several hundred miles, do you expect still to find the Bend upon the Ellenberger? Look what you have in the Oklahoma Trough. You have Silurian, Devonian and Mississippian below the Bend. Why shouldn't some of those come in?

Mr. Pratt: Certainly, the beds beneath the Bend in Stephens and Eastland Counties can be definitely correlated with the Ellenberger which underlies the Bend in San Saba County.

Mr. Buttram: With reference to the Bend Arch I have certain data which may be of interest. In the northern part of Brown County there are several wells drilling and drilled in comparatively close proximity. According to my correlation of

the well records, and I think it can be fairly well determined, although there are those here who may take issue with me, the Grosvenor well located some four to six miles west of the Sinclair well gets the top of the Bend lime at about 490 feet below sea level. The Bailey well, about two miles west of the Partridge well encounters the top of the Bend at about 202 feet below sea level. The Partridge well gets the top of the Bend at 94 feet below sea level, while the Bartles and Dumenil encounters the top of the Bend at 524 feet below sea level. After having studied these different well records I think one is fairly safe in at least drawing some general conclusions because certain formations there to my notion stand out rather conspiciously, and if I am right in the correlations these tests certainly prove the Bend Arch, and I was very favorably impressed with the closeness of the original report to the real Bend Arch as proven by these tests.

Mr. Kennedy: Some things that have been said I agree with, and some I don't, but I agree with Mr. Pratt in interpreting the logs. If we get alongside of the driller and don't go too much on the scientific side of it, like a good many of our young geologists do, we get a great deal of information that the written logs don't always tell you.

Mr. Udden: I have about 400 logs. I have plotted a lot of them. I started to work out a subsurface contour map on the black lime. I went home that night and tried to sleep, after I had finished the contouring. It was almost impossible for me to sleep. You can get almost anything you want for structures by working the top of the lime.

I want to call your attention to one horizon in which I pin more faith than almost any other, up to the present time. You have probably heard that term "Ellenburger." There is a limestone by that name, and I believe that I have samples now from about eight or nine wells, probably a dozen in this rock. The character of that limestone seems to be about the same, from Runnels County to Eastland County and then south into Brown County. It is probably one of the best horizon markers that I have run across.

And then there is another place to check this. You have heard of the Lower Bend Shale. Well, there is about 125 feet of that, and you can contour on the contact of that Bend Shale

and the gray limestone. You get something by contouring this plane. I believe if you can take the Ellenburger limestone and contour that you will find something interesting in regard to that Arch we are talking about, get some thing that is quite satisfactory. I merely call your attention to it; it may be of some help.

Dr. Bloesch: I think the way you pay the driller has probably something to do with where he finds the black lime. If you pay the driller so much a foot until he gets to the black lime and then so much a day, he can make more by the day than he can by the foot and consequently he will find the black lime as soon as possible. The method of paying the driller by the day after he gets down to the black lime ought not to be used when securing data for subsurface structures.

Mr. Eckes: Some accurate information is to be obtained from the drillers record. When the drill is passing through a characteristic shale, the drillers usually report it as such, and when they pass into a characteristic lime, they usually report it as lime, but when the formations grade into each other, the driller simply guesses at the formation he has; in fact no one can tell what the formation is without making an analysis. The drillers are often misled in naming formations by other factors—if a puff of gas is obtained in a lime formation, many drillers call it "Gas Sand" and if water is obtained in a lime formation, they call it "Water Sand." We examined the samples called "Water Sand" by one driller, and found it to be white lime without a grain of sand in it. By making a careful study of all of the well logs I think we can correlate some of the formations, but in particular cases we can't pay much attention to the well logs. In some localities the formations are much more characteristic than in others and the well records are fairly accurate.

Mr. Bloesch: I would like to ask Mr. Eckes if he ever asked the driller to keep a record of hard and soft formations. That makes quite a difference in following a well log, for the simple reason that anybody that ever worked that way, with a standard or rotary drill, can tell whether it is hard or soft. If it is soft, the drill will go right through it, and if it is sandstone or limestone they can pick them out right away, and anybody that has ever worked on a derrick can tell them.

Mr. Eckes: Yes, we keep a record of the depth, color, feet drilled per hour, driller's name of formation, and we make an analysis of the samples microscopically and chemically and determine the percentage of lime, sand, chert, shale, etc. We also note the hardness, compactness, cavings, oil, gas, water, etc.

Mr. Pepperberg: While I do not believe a close correlation can be made in the wildcat wells which do not produce oil, I do believe by a pretty close study we can find zones that we can map with some certainty.

Now in the Ranger district, to get back to well logs, you have to know, for one thing, whether a company is running its own drills, because if the driller is employed and he has a little trouble and there is no one at the well at the time, you can depend on it that the log will show hard lime. If the well is contracted the log usually shows hard black lime as soon as the Smithwick shale is reached because the contractor usually gets more money for drilling after the black lime is reached and it is only natural that he should find it a few hundred feet higher in the well than it should occur. By getting the drilling reports and logs of adjacent wells and comparing them carefully with the reports and log of the well under investigation, you can be sure they are not in anything like what we really know to be black lime or gray lime. In the Ranger field there are two sands, if I may call them such, which are about 200 feet apart. Two or three wells are producing from the upper horizon, and below this upper sand there is a limestone. I have arbitrarily used this limestone as a datum upon which to contour the subsurface structure. I do not contend that I can determine this limestone from a well log in eastern Palo Pinto County, but I believe the Smithwick Shale interval can be roughly determined and I believe further that the absence of the limestone in Palo Pinto wells can be accounted for in another way than by assuming that the lime necessarily pinches out, because if we have a syncline, we might have a greater thickness of Smithwick deposited in this hole than is found in the region to the west. I do not intend to say that this anticline or syncline is proof of the fact because they are hypothetical. If you will study your logs and drilling reports carefully you will find sufficient data upon which to construct a subsurface structure map which will be of untold

value in pointing the way to the most favorable places for drilling for oil. The true value of a subsurface map is to point the way before development and to eliminate as far as possible the chances of failure. I contend that we have sufficient tools to work with at the present time for this work because several predictions based on this data have already proven correct. I recommend that you get the drillers reports, the logs, talk with the drillers, make your comparisons and draw your conclusions before the fields are drilled up. After a field is fully developed a subsurface structure map is merely of scientific interest.

Mr. Perrine: In this connection should be considered not only the top of the sand or the top of the Ellenberger, but the top of the formation at which the well starts. There is a sand almost universally present near the top of the Canyon formation (the basal Cisco bed), and this horizon is one which I think we all ought to consider more or less in making our correlations, as well as the formations lower down. Mr. Drake's paper, which is one of the earlier reports of the Texas survey, divides the Canyon formation into twelve different subdivisions, and the topmost division he lists under the term "Campophyllum torquium beds". Anyone who has studied paleontology should have no difficulty in recognizing that particular fossil, which is found abundantly only in that subdivision of the Canyon. There are some other formations below this one which can also be readily followed and correlated.

Along with this I wish to make a remark with regard to folding in the Pennsylvanian. Dr. Schuchert was asking something about the folding in the Pennsylvanian. In Section 51 of the H. T. & B. R. R. Survey, Brown Co., Texas, where the Partridge well is located, there is a very pronounced unconformity in the Pennsylvanian, the Upper Canyon beds lying practically horizontal, the lower ones dipping from 15 to 20 degrees to the south and southeast. This very sharp bend or dip in the underlying beds is right on the crest of the Bend Arch, as we call it.

Mr. Deussen: I wish to ask Dr. Schuchert to give us a brief talk regarding the distribution of the sand in Bend times. Mr. Plummer touched on that question.

Mr. Schuchert: Gentlemen, that is a very hard proposition to put up to me, because it involves probably a hundred antecedent questions that should be settled first, but before I come to that, let me say a few things that especially strike me in this discussion. It seems that you have as great difficulty in correlating your Bend, or your supposed Bend, as we paleontologists have had with our fossils. You are in difficulty, you are in great dificulty, and you need a paleontologist above all things. The discussions here this afternoon remind me of some of the happy discussions I used to listen to in Washington twenty to thirty years ago when the official geologists tried to make correlations based on lithology. What are your correlations based on today? Are they based on lithology? What characterizes your Pennsylvanian? What characterizes your Comanche, or your Chester, or for that matter any post-Proterozoic horizon? Isn't it fossils? And yet you gentlemen are trying to correlate a horizon from place to place, because it is black, because it is a limestone, or because it is gumbo! As you have shown in this very discussion, the drillers will contradict themselves. What is called shale by one is limestone to another, and they will call a gray thing black. How can you make your correlations on that basis? You cannot do it.

Now let me make a strong plea for fossils. We do not expect you to bring out a fossil as big as a hat—not at all—but we expect you to bring out a *fossil.* It may be *Endothyra baileyi* or *Fusulina secalica,* or some other form. We can then study it and tell you something about it. In the paper that I propose to read to you at some other time, I will point out some things a paleontologist can do with fossils, and even with microscopic ones.

Now we come to the possibility of sands. That involves the whole question of paleogeography, and before any man can make a paleogeographic map he must begin with a limited geologic horizon, and that horizon has to be based on fossils and lithology—for without lithology he can not tell whether it is going toward the shore or toward deeper waters. Some of these seas were not very deep, only one, two, or at most three hundred feet, and often much less. Therefore you may expect a marked lithologic change within a few miles. Only this morning a good

geologist told me that he knew of a thick limestone that changed into shales in ten miles. If a limestone gives out in ten miles, you may expect other marked changes. Now, as I said a while ago, in regard to the whole Bend problem, the Ellenberger is the horizon to depend on. It is known here in Texas, and its equivalents are known in Oklahoma. In the Bend country that is the dependable horizon to start from, but above it you may be anywhere in the late Paleozoic. The actual horizon encountered depends on what your fossils show, in fact, correlation depends altogether on the fossils. In the northern part of Texas you may yet turn up Silurian or Devonian, and as one proceeds toward the Ouachita geosyncline the Bend series may not at all be in contact with the Ellenberger dolomites.

THE BEND FORMATION AND ITS CORRELATION

By G. H. Girty, *Washington, D. C.*

Before considering the correlation of the Bend formation it is necessary to recognize that the Bend is two things, not one, that it is divided by an important unconformity and that the lower part is of Mississippian while the upper part is of Pennsylvanian age. Though it was rather clearly intimated in the Llano-Burnett folio published in 1912, that an unconformity occurs within the body of the Bend formation, the statement seems largely to have been lost sight of and it was not practicable in a publication of that type to give the subject the consideration which it perhaps deserved.

The evidence supporting the inference that an unconformity exists within the Bend formation was largely obtained in 1910 in the course of field work in San Saba, Lampasas, and Burnett counties. The observations and collections made at that time are supplemented by collections from the same area previously made by other geologists, and by important material from equivalent strata in Oklahoma and Arkansas subsequently acquired.

The Bend formation, as it is at present recognized, consists of two shales separated by a limestone. The lower shale has not yet received a distinctive name but the limestone above it has been named the Marble Falls limestone and the upper shale has been named the Smithwick shale. The supposed unconformity occurs between the lower shale and the Marble Falls limestone and its existence is indicated by the facts: (1.) That the lower member is of Mississippian age, whereas the middle and upper members are Pennsylvanian; and (2.) that the lower member is irregular in its distribution so that the Marble Falls limestone in some areas, as at Marble Falls itself, lies directly on the pre-Carboniferous without any intervening beds of Mississipian age.

The Bend faunas have not been made the subject of detailed paleöntologic study and but few of the species have been described and illustrated from specimens obtained in Texas. Four or

five of the species described by Roemer in his Kreidelbildung von Texas are probably from this formation. Cummins described Hadrophyllum aplanatum. Hyatt, and later Smith, described and figured a number of cephalapods. And this is about all. It has been possible to locate all these species in the different members of the Bend, and their stratigraphic occurrence explains a certain conflict of evidence that has existed as to the age of the formation. Indeed, the dual nature of the Bend is doubtless the cause of the opposing views that have been held as to its age. The forms described by Roemer, if they are Bend at all, were with doubt obtained from the Marble Falls limestone. Hadrophyllum aplanatum has been found only in the Smithwick shale and appears to be one of its characteristic species. Large nautiloids seem to be rather characteristic of the Marble Falls limestone and the two species described by Hyatt (Metacoceras walcotti and Stearoceras gibbosum) came from that horizon. Goniatites crenistria (*Glyphioceras incisum* of Hyatt) is abundant in the lower Bend but I have not found it in the middle or upper parts of the formation. The same is true of *Goniatites striatus* (Hyatt's *Glyphioceras cumminsi*) and of *Gastrioceras entogonum*. *Paralegoceras iowense* occurs in the Smithwick shale but not, so far as shown by my collections, in the Mississipian part of the Bend. *Gastrioceras Compressum* was described from the Marble Falls limestone but is much more abundant in the Smithwick. It does not occur in the lower Bend. *Paralegoceras texanum* is probably a Marble Falls species though as a matter of fact it has not been recognized in any of my collections.

Smith, apparently with considerable confidence, refers the Bend to the St. Louis-Chester stage of the Mississipian, largely, I think, because he identified in the fauna *Goniatites crenistria* and *G. striatus* both of which occur in the Upper Mississipian rocks of Arkansas and are characteristic also of the same horizon in Europe. On the other hand, *Paralegeoceras iowense* which Smith, as well as Hyatt cites from the Bend is a Pennsylvanian species described from Iowa and some other cephalopods have distinctly Pennsylvanian affinities. But Goniatities crenestria and G. striatus occur only in the lower Bend, and Smith was, I believe, right in identifying this part of the Bend as Mississippian. On the other hand, Paralegoceras Iowense and other

types having Pennsylvanian affinities occur only in the Marble Falls limstone and Smithwick shale, and I believe that they too are right who identify this part of the Bend as Pennsylvanian. Thus, the Paleontologic evidence, which at first seemed conflicting, falls right into line when the species are referred to their proper horizons in the Bend.

It would be tedious to comment in detail on the paleontologic features of the three faunas that occur in the Bend, but a few points are worthy of note. The fauna of the lower Bend is rendered striking by the abundance of cephalopods, chiefly three or four species of goniatites, of one or two species of brachiopods belonging to the Leiorhynchus, and of one or two species of pelecypods belonging to the genus Caneyello. Other forms are less abundant or less striking though 35 or 40 species have been obtained from this part of the Bend. Much the same association of species occurs in the Caney shale of Oklahoma and in the Moorefield and Fayetteville shales of Arkansas, and these are believed to be equivalent formations. In Arkansas the related faunas contain forms characteristic of, or occur associated with, faunas comparable to the typical Chester faunas of Illinois and Kentucky.

A marked faunal change takes place between the lower Bend and the Marble Falls limestone. Not a single species is definitely known to be present in both formations. If any species are held in common they must be very few and must belong to types such as Orthoceras in which specific discrimination is very difficult.

The faunas of the Marble Falls limestone and Smithwick shale, though they can easily be distinguished, are clearly related to one another and have a number of species in common. The fauna of the Marble Falls limestone as represented in the Survey collections from Lampasas, Bend and Marble Falls, would probably not fall much short of 100 species. The Smithwick fauna, on the other hand, is known only from two collections, one made at Bend, San Saba County, and the other apparently on Honey Creek in Burnet County. The Smithwick fauna, so far as known, comprises only about 35 species.

Though they present many novel features, the faunas of the Marble Falls limestone and the Smithwick shale would scarcely be mistaken by any paleontologist of experience for anything but Pennsylvanian faunas. One of the common fossils wherever the

Marble Falls limestone occurs is *Chaetetes milleporaceus. Campophyllum torquium* is also abundant in places, and likewise, large echinoid spines. At Marble Falls I collected, apparently almost in place, a production of the genus Tegulifera (or Richthofenia?) and at Lampasas a species of Meekella. A new species of Martinia, a genus unknown to the Pennsylvanian faunas of Eastern North America, was found in the Marble Falls limestone between the hamlets of Nix and Bend. At Marble Falls several species of Pseudomonotis were collected, though the type is not abundant. The fauna of the Smithwick shale is peculiar. It not only contains a number of undescribed species and a number of peculiar ones, but it is largely lacking in those types of brachiopods which abound in most Pennsylvanian faunas. A small and primitive Fusulina occurs in the Honey Creek collection and at the same locality a peculiar coral, apparently belonging to the genus Paleacis, a type heretofore found in America only in rocks of Mississippian age. Another peculiar coral, which, as it occurs in both of my collections from the Smithwick, may probably be considered one of its characterictic fossils, is Hadrophyllum aplanatum.

The Marble Falls limestone and Smithwick shale are therefore believed to be of Pennsylvanian age and they can be correlated with a high degree of probability with the Wapanucka limestone of Oklahoma and farther north with the Morrow formation of Oklahoma and Arkansas. A bed of shale associated with coal in the middle of the Morrow formation in northwestern Arkansas has furnished a fossil flora that proves it to be of Pottsville age, either late middle Pottsville or early upper Pottsville.

The pre-Pennsylvanian unconformity is one of the most widespread unconformities in all the Paleozic rocks of North America. Pennsylvanian deposits rest in different regions upon rocks of all ages from pre-Cambrian to Upper Mississippian. In very few areas, if any, is there a complete transition from the Mississippian to the Pennsylvanian, and as a rule wherever the Pennsylvanian contact occurs, there an unconformity can be recognized. Very rarely, however, is this unconformity accompanied by any marked discordance in dip, at least if the underlying rocks be of Mississippian age. On the other hand, a basal conglomerate is commonly present; the underlying strata are in many places

uneven and eroded; and a more or less profound change of fauna and flora marks a lapse of time represented in the more complete sections by deposits bearing characeristic fossils. The facts presented seem to warrant the belief that this widespread unconformity is represented in the Bend formation by the break between the lower Bend shale and the Marble Falls limestone.

It may seem somewhat paradoxical and disappointing to have the boundary between Mississippian and Pennsylvanian modestly disposed in so unconventional a place as the midst of the Bend, and this is especially true if one has in mind the eastern United States where the beginning of the Pennsylvanian is heralded by massive sandstones and conglomerates. In the southwest, however, in parts of New Mexico and Arizona, the contact between Mississippian and Pennsylvanian is almost indistinguishable, save by paleontologic means. The rocks of both series there consist of limestone, so similar in character as to be practically indistinguishable and so closely in contact that they have been mapped as a single formation. Nevertheless, Fusulina and the common route of Pennsylvanian fossils can be collected only a few inches from fossils of lower Mississippian age. Thus, in the midst of this apparently uniform limestone occurs a break which represents all of upper Mississippian and probably part of Pennsylvanian time, and which correlates with the widespread unconformity that everywhere occurs between Mississippian and Pennsylvanian, and is in many places so impressive as geological phenomenon. The Bend, therefore, merely partakes more of the conditions of the extreme southwest than of the extreme northeast. It the Bend this unconformity probably does not represent a long stretch of time, but what is important in the present connection it may represent a considerable thickness of deposits.

The Caney shale of Oklahoma, exposed in the Arbuckle and Ouachita mountains, is a formation about 1,000 feet in thickness, consisting largely of black shale, though the upper beds are of a lighter brownish gray color. The Caney fauna, which resembles that of the lower Bend, occurs in the middle and lower parts of the formation so that the paleontologic evidence points to a correlation of only the lower 500 feet of the Caney with the lower shale of the Bend.

In some areas the Caney is overlain by the Wapanucka limestone which correlates in a general way with the Marble Falls limestone and Smithwick shale. Fossils are scanty in the upper light-colored part of the Caney and faunas thus far obtained are difficult to interpret. They consist mostly of small gastropods and palecypods, many of which have related species in both the Mississippian and Pennsylvanian. It is at least clear that the upper Caney fauna is widely different from the peculiar fauna of the lower Caney, and a preliminary examination indicates that it is allied to the fauna of the Wapanucka limestone. Indeed, a rather meager fauna from some shales above the Wapanucka limestone, but below the Chicky-Choc, presents a similar facies, so that tentatively the Pottsville in this region (the McAlester quadrangle) may be regarded as consisting of a limestone between two shales, of which latter the lower shale has been included in the Caney and the upper in the Atoka formation. At any rate, whatever proves to be the relation of the two shales, the correlation of the Wapanucka limestone and the Marble Falls limestone is strongly suggested.

In northwestern Arkansas and adjacent parts of Oklahoma the Marble Falls-Wapanucka interval is represented by the Morrow formation and the lower Bend-lower Caney interval by the Moorefield and Fayetteville shales, one or both. In this region, however, there intervenes between the Fayetteville shale and the Morrow formation another group of rocks, the Pitkin limestone, which has no known representative in the areas where the Caney shale and Bend formation are developed. It is at least a plausable hypothesis that the absence of the Pitkin limestone may be due to the pre-Pennsylvanian unconformity.

The fauna that occurs in the lower Bend runs through perhaps 500 feet in the Caney shale. No locality was found favorable for measuring the lower Bend shale but is was evidently at its maximum far less than half as thick as that part of the Caney, and of course, in some areas it was absent altogether. That the sediments in Central Oklahoma are excessively thick, and that they may fairly be expected to thin out in whatever direction they are traced seems very likely, but it also seems likely that in central Texas erosion also has been effective in thinning the

lower Bend. The thickness of the lower Bend may, therefore, vary materially at relatively nearby points.

In western Texas and New Mexico the Pennsylvanian rocks show a profound overlap. In places the Mississippian is absent entirely and in places it is present, but unlike the occurence in central Texas, it is not the upper Mississippian. but the lower that is found. Not until one passes over into Utah, Nevada, Idaho and Montana does he discover anything to correlate with the lower Bend, which must therefore wedge out under ground to the west and northwest. Whether the Pottsville part of the Bend, the Marble Falls limestone and the Smithwick shale are represented in this direction is a good deal of a problem. In some areas of outcrop in west Texas and New Mexico there seems substantial evidence for believing that the lowest Pennsylvanian sediments are Pottsville and do represent the Bend, while in others the earliest Pennsylvanian sediments, by their faunas, appear younger. It is possible that such a real difference in geologic age does exist and that it is connected with the unconformity that occurs between the Bend and the Strawn and that apparently marks the transition from the Pottsville to the higher Pennsylvanian. Of course, any correlation of the Bend (Marble Falls limestone and Smithwick shale) with rocks farther west, has a large element of speculation and requires substantiation by more complete evidence and a more careful collation of it than I make claim to. The question is furthermore complicated by the changes which the faunas undergo in passing into those western areas where they show a greater resemblance to the faunas of Asia than to those of the upper Mississippi valley.

It may pertinently be asked whether the facts touched on here have any practical bearing upon the problem of obtaining oil from the Bend formation. The fact that an unconformity occurs within the Bend points to probable irregularities in thickness and distribution of the lower member, but the fact that the oil is obtained apparently from the Marble Falls limestone, and above the unconformity, renders these irregularities of little moment in drilling. The hypothesis is worth considering, however, that the source of the oil found in the Marble Falls limestone is the lower shale of the Bend, and that the oil has not migrated far from that source. If this were true, the distribution of the lower Bend

shale and its variation in thickness would be matters of considerable importance. To prove or disprove such an hypothesis, it would be necessary to examine records of drillings that passed completely through the Bend to the pre-Carboniferous basement rock. Such an examination I have been unable to make. The few records that I have examined have with one or two exceptions been those of successful wells where drilling stopped with the penetration of the oil zone. Farther inquiry into this question, if farther inquiry seems profitable, rests then with others.

DISCUSSION

David White: I wanted to ask what the logs of the wells show, so far as those wells are reliable, as to the depth of the Bend, that is beneath the Marble Falls limestone.

Mr. Plummer: In all the well logs we have examined the lower Bend shale has been present at from 160 to 200 feet below the Ellenberger.

Mr. Moore: I think in this connection it may be of interest to report informally paleontologic studies which I have recently made in which about 166 distinct species from all horizons, including a basal shale mentioned, have come under my observation. There seems to be no doubt at all that the Bend formation must be correlated with the Pennsylvanian. To that extent the evidence which I have reviewed agrees entirely with that read by Dr. White from Dr. Girty's paper, and also Mr. Snider's report of Dr. Weller's report. The large fauna. which it has been my privilege to examine while containing undoubtedly Mississippian forms, is, as Dr. Girty has said, without any question a basal Pennsylvanian fauna.

David White: I would like to add a chapter to Professor Schuchert's Book of Lamentations on the sinful frailties of the driller and the need of paleontologists.

There are not many paleontologists in the country, I am very sorry to say, who are competent to work up the Foraminifera, and yet it is surprising how many formations contain Foraminifera, and how widely distributed they are. They are more widely spread than is supposed, and the time is coming when they will be made of a very great use by the driller and by the oil and gas geologists.

A feature that impresses me always in a meeting of this kind is the fact that oil and gas geologists are striving with every effort—theoretical geology and every other means—to acquire new criteria by which to discover new oil pools. Paleontology is one of these means, but I am impressed with a doleful lack of efficiency in our present work; a failure to secure valid detailed logs and cuttings. Your knowledge of the characters of the cuttings and fossils seems, from what you say, to be baffled by the unregenerate driller. So we listen to cheerless lamentations and despair.

Now it isn't exactly my personal job to labor with the driller. I wish it were; I would like to try it. Probably I wouldn't do any better than any of you, but I would like to ask you—is it not possible that after all, your failure to get adequate and accurate well criteria may be due to the fact that you are not in cordial contact and sympathy with the driller? The driller is drilling, but he seems to have little interest or incentive to gather the data for which you must depend on him and the intelligent collection of which would make his task so much more interesting to himself. His ability and intelligence are not inferior to yours. Are you doing your best to bring him to a better basis of operation? How many of you are conducting schools? How many of you put aside your high-brow clothes and forego your high-brow langauge (which is worse than high-brow clothes) and so present the subject of rock characters that he, recognizing them, will take pride in good logs and in gathering the samples to serve as vouchers for his identification? Heaven knows you will never get the material you so badly need, they will never get it for you and they will never try to, unless you interest them in finding the truth and in learning how to apply it.

Mr. Beede: I would like to make one remark regarding the use of Fusulinas in the correlation of horizons. I have ground up a thousand or two specimens from various formations in this country and in Europe and Asia, and I am firmly convinced that any horizon can be located within a few hundred feet by the Fusulinas. When they are present they are as good criteria for determining horizons as the Ammonoids or any other group of fossils. If you have copious cuttings they are easily obtained. All you need is a piece from which you can get a cross section

through the center, and then of course if you can get a whole one from which you can get a longitudinal section through the center, it is that much better, but with a very close examination of the cuttings you get from the well I know you will be able to obtain specimens, I have already studied, some of these from cuttings in wells and I think careful practice in this connection will reveal a great deal of data that we are not able to get without them.

Mr. Cummins: It seems that somebody has found the Smithwick in the Bend. Probably it is there. I don't know. I collected the fossils from there that were first collected. The cephalopods were submitted to Dr. Hyatt and the vertebrates were submitted to Dr. Newberry. Now I understand that Dr. Girty suggests that the Bend as first determined and first named belongs to the lower part of what we call the Bend Series. At the time this was named the Bend, the Marble Falls and the Smithwick were included in that series, because I put in the Bend only what occurs in the Bend. Of course there is no objection to including more, but it seems rather confusing if you put a part of the Pennsylvanian with a part of the Mississipian and call them all Bend; it confuses us a little when we consider that. Now I do not believe that the Bend, the lower part of it as we now understand it, belongs to the Mississippian. I am supported in that conclusion by Professor Hyatt in his determination of the cephalopods, and by Dr. Newberry in his determination and letter to me about the vertebrates I sent him. Now these collections of fossils determined by J. Perrin Smith, were collected by myself, near the eastward margin of the Bend, a few miles down on what I considered the eastern dip of the Bend at the time. He suggests that they belonged to the Chester, and so there was some conflict, but in determining the age of horizons, whether I am right or wrong, I do not know—I know very well that one swallow does not make a spring—but when I am traveling across the section and come to a fossil that the eminent geologists have told me belongs to a certain horizon, and to that horizon only, I believe I am on that horizon. If they say it is Carboniferous, I believe even though I found only one of those fossils, that it is Carboniferous.

Now in correlating, I commenced to run a line of levels from

Albany across the country in a northwestern direction. I found no sample of the Permian fossils until I got to the western part of the county, in the Clear Fork of the Brazos, and I got the well-known characteristic fossils of the Permian vertebrates; I know that is the Clear Fork division of the Permian. I went on to the westward, put in the higher horizons at the foot of the Staked Plains, then went north and ran a line almost directly east across my Double Mountains of the Permian. After leaving the Triassic I came across the Double Mountains again, and then I ran a line to the Clear Fork and from the Clear Fork to the Wichita division of the Permian, or to the Wichita beds, so I found the Wichita beds and Albany beds occupying stratigraphically the same place, so I abandoned the name Albany. Now I did that because I found no fossils to determine that they belonged to the Permian in that part of the country, and when I found Permian then I said Permian. Now at the very base of what you call the Bend I first found fossils, as I said before, said by Dr. Newberry and by Dr. Hyatt to belong, and to have been found only in the Pennsylvanian, and so I concluded that the older fossils were more likely to come up into the newer than that the newer should originate down in the older. I say, therefore, that one fossil might determine the whole thing, so far as I am concerned. If it belonged definitely to a certain horizon somewhere else, I would say when I found that bed that it too belonged to that horizon, and that is why I say the Bend, the whole Bend, belongs to the Pennsylvanian. I don't believe that the weight of evidence, that the number of fossils that you find in a certain bed, would determine it. It might be the determination of fossils would determine the horizon, but not when the distinction is to be made between the lower Carboniferous and, as we used to call it, the Sub-Carboniferous or the Carboniferous proper, or the Mississippian and the Pennsylvanian.

OIL-BEARING FORMATIONS IN TEXAS

By J. A. Udden, *Austin, Texas.*

I shall begin by stating that as I understood it my remarks should be directed more to the general public than to the professional men who are present here. I have followed that request, and if the professional men should find some of my remarks commonplace I trust that you will excuse me. As I look at it, it is of great importance that we all should have a little understanding of geology, and so to speak, absorb a little of the science. By so doing we will, without really being conscious of it, adjust ourselves to the demands upon us in the way of knowing things connected with the geology of petroleum.

No less than 97 per cent of the surface of the State of Texas is covered by sedimentary rocks; rocks that have been deposited in water. If when we speak of a formation we limit the use of this word to sedimentary rocks that have not been greatly altered, we can almost say that every formation in the state is oil-bearing; that is, almost every formation in the state contains at least a minute quantity of material from which oil may be distilled. The thickness of sedimentary rocks in this state varies from zero to probably twenty thousand feet, and I presume that ten thousand feet would not much exceed a fair average for the thickness of these rocks over the entire state. For an inconceivably long period of time this part of the American continent has been in the making. Sometimes it has been below the sea, at other times it has been above it. It has never been at rest. These changes of level have been imperceptibly slow. Going back in time as far as the earliest recorded animal life, there must have been since then half a dozen submergences, alternating with an equal number of periods during which our land was above sea-level and undergoing erosion. The periods of emergence probably lasted just as long as the periods of submergence. During every period of submergence there was an accumulation of slime, mud, sand and gravel at the bottom of the water. All this material was derived from lands at other places undergoing erosion. With

every change of currents in the sea, caused by general and gradual movements of its bed, and of the surface of the land, there would also be changes in the accumulating deposits. Where for a hundred thousand years calcareous slime had been depositing over extensive areas, elevation of the bottom might result in a cessation of the deposition of the calcareous slime, and change to the building up of thick strata of mud and clay. By some other geographic change the deposition of clay might cease and be followed by a deposition of sand. A more or less well marked body of deposits made under more or less identical physical conditions is what we call a formation. The great number and variety of formations is the result of the innumerable slight differences in physical and geographic conditions that have prevailed in all ages of the past in different parts of the sea. But going as far back as we know of the past, there is one condition that has always been constant. Animals and plants have always been present in the seas, and their remains have always added something to the sediments which have been forming. Even in the earliest sedimentary formations that are known, we find evidence of the existence of living things. The earliest fossils that have been discovered in the most ancient fossil-bearing rocks show that life at this stage already was highly organized, and that it must even then have existed for an immeasurable length of time.

Plants and animals have apparently in all ages been able to adjust themselves to the ever-changing conditions of existence, brought on by the physical changes on the earth. Every part of the sea is inhabited today. Even the Artic seas are teeming with certain low forms of life, and the continuity of life from the earliest forms known to those of the present day cannot for a moment be doubted, though it is evident that at certain periods, conditions for life have been more favorable than at others.

The fact that petroleum is the result of a slow distillation of organic material imbeded in the debris that has accumulated in the deposits in the sea is now so well established that it requires no discussion at this time; and remembering the continuous presence everywhere of living things such as plants and animals, it follows that every formation, at least when it was first made, contained some organic material from which oil and gas

may have been made. Tests made on all kinds of sedimentary rocks support this conclusion. Even sandstone that originally formed extensive bars and beaches along the sea coast contains animal remains. Clays, shales and limestones, originally forming slimes and mud in the more quiet part of the sea, are very rarely devoid of organic materials. The remains of microscopic organisms and shreds of tissues of larger animals have settled in the sea with the mud of such localities and no doubt were more effectively buried and preserved than organic remains buried in more open sands. No doubt in every age of the past by far the greater amount of organic material underwent decay and destruction and returned to the elements; but considering the slowness of the accumulation, the burial of even a small part of the organic world continuously would result in the preservation of an enormous quantity of organic compounds or their derivatives, in the stratified rocks of the earth. Various estimates on the bitumens thus preserved in practically every formation from which it has not lately been expelled by heat and pressure, indicates that if all of this material could be separated from the sedimentary rocks of the State of Texas, it would be sufficient to form a layer several feet thick over its surface.

The oil fields in America, if not all of the oil fields of the world, may be classified in three groups; fields in which the oil occurs in strata which have been more or less flexed or folded; fields in which the oil occurs in salt domes; and fields in which oil occurs in volcanic rock. It is also a fact that if we consider the different forms, he different kinds of oil fields we have in the State, there are more forms represented than any other State.

Until three years ago we had not found any oil in commercial quantities in igneous rocks in the United States. The finding of oil in igneous rocks in the Thrall field was an unusual occurrence. This field is, as you know, located in the eastern part of Williamson County. This county is underlain by sediments of Cretaceous age more than 3,000 feet thick, but it is really not in these sediments that the oil in this field was found. The wells of the Thrall field go through the greater part of the Taylor marl. On reaching the depth of from 800 to 900 feet, most of the productive wells enter an igneous rock. Originally this rock was a basaltic lava, but it has been changed to a soft and somewhat

porous serpentine and it was this porous rock that contained the oil. From a study of nearly all the well records from this field it is evident that the body of this rock underlies something like a square mile of territory. In one place the rock reaches the thickness of several hundred feet. It has the form of a lense convex on the upper side. Its average thickness in the center of the field is about 60 feet, and from this point it thins out in three directions to a feather edge. How it terminates to the west is not yet determined.

What has happened at Thrall appears to be something like this: During the Cretaceous age most of Texas was part of the sea which extended from Alaska to the Gulf of Mexico. In this sea a thousand feet or more of sediment had been laid down in this region during the lower Cretaceous age, and still later another 500 feet of chalk and shale had been deposited during the upper Cretaceous times. When some 150 feet of marls had been laid down on these earlier sediments, an eruption occurred on the bottom of the sea and deposited a low volcanic cone of the dimensions stated. Similar eruptions took place at the other points along the Balcones Escarpment at about the same time and volcanic dikes and sills were injected into the Cretaceous sediments in Travis County, Medina County near Uvalde, and even as far out as in Kinney County. Igneous material belonging to this period of volcanic activity is nearly all of the same kind. It consists of very heavy dark basaltic rock. After these eruptions took place sedimentation went on in the sea as before, and extrusions and other material which probably did not reach the bottom of the sea but remained as intrusive in sediments below the bottom of the sea, were all buried under a cover of probably 2,000 feet of marls and sands in the same ocean.

The marls of the upper Cretaceous formation are quite rich in animal remains of all kinds, but especially of the small microscopic kind that live in the water at the surface of the sea. In almost every pound of marls of these formations there is sufficient organic material today to produce a considerable distillate of oil, if the marl be heated in a retort. The igneous rock which became imbedded in this marl was subjected to a change that altered its chemical composition, principally by the taking up of a great deal of water. It is probable that this action resulted in

fracturing the rock extensively and in making it porous. After the rock had thus become porous or while the change was still going on, organic bituminous material crept into it, or was absorbed by it by capillary attraction, from the shales or marls surrounding it. The igneous body has later been tilted and it is not impossible that some of the original oil filling the serpentine has been spilled, so to speak, by the tilting of the formation holding the oil. At any rate, the lower part of the rock was found to be partly filled with water.

It does not seem impossible that other bodies of similarly placed extrusives may yet be found and the question has been asked, what the chances are for finding other oil pools of the same kind. I believe that these chances are very small, indeed. Intrusive bodies of the same kind similarly situated can be looked for in a belt 10 to 20 miles wide, bordering the Balcones Escarpment. It is evident that no igneous rock can be oil-bearing unless it be made porous by metamorphic changes. Most of the volcanic rocks seen in the belt already referred to are not in this condition.

The salt dome fields are as yet but imperfectly understood. In Texas alone it is represented that some thirty-four salt dome structures have been discovered. A few of these are in the northeast part of the state and have mostly eroded away. What is left appears to be the basal part of these structures. Such are the Grand Saline and the Brooks Saline. One large group of these structures is distributed over Jefferson, Hardin, Liberty, Harris, Galveston, Brazoria and Matagorda Counties. A third group is indicated for San Patricio, Duval, Brooks, and adjacent Counties. It will be understool that not all of these are oil-producing. More than half of them are as yet barren. But that all of them are essentially of the same kind and that they have been producd by the same conditions seems to be quite evident.

The most conspicuous feature of these structures is that they contain at a greater or less depth, massive domes of salt. The salt is overlain by gypsum and dolomite that, like the salt, evidently have been introduced or built up in the position they now occupy and do not belong in the series of sediments in which they now occur. They have been produced at a later day. It is evident that the salt in these fields has slowly forced its way, or built itself upward, lifting the entire mass of overlying sedi-

ments. This lifting has been so slow that the erosion of the surface of the ground appears in most cases to have kept pace with the slow elevation of the land surface. It is only in a few cases that the elevation of the ground has exceeded erosion and that the surface of the ground over the salt domes now has a slightly higher elevation than the flat surface of the surrounding country. In the Spindle Top field this difference in elevation amounted to only a few feet. Damon Mound rises some 70 feet above the general level of the surrounding coastal plane. Bryan Heights and High Island are other instances of this kind. In some of the salt dome fields the ground water appears to have dissolved the higher part of the salt dome and this has resulted in a general sinking of the land as at Sour Lake.

What has caused the slow accumulation of the salt underground in these fields is not as yet known and I shall not attempt to discuss this question. These fields are limited in extent. The oil is held usually in a cap rock which overlies the salt. The cap rock consists mostly of dolomite and is frequently coarsely crystalline and highly porous. It is from the lower part of this cap rock that the great gushers are supplied. The enormous production from this part of the salt domes lasts usually only a few years. In several of the salt dome oil fields production has been prolonged by the finding of oil under clay formations that lap up over the sides of salt domes, in many places at high angles. In the Humble field rich minor pools of this kind have been drained by wells bored a mile or more out from the center of the field to depths of as much as 4,000 feet.

The conditions under which oil has been retained underground in these fields are in some sense like those in other fields. The close-grained clays and marls and the tight upper part of the cap rock have prevented the oil from coming to the surface and thus escaping. The overlying clays and the cap rock form inverted basin in which the oil is held by the upward pressure of the ground water. No special explanation of these conditions is necessary. It appears that the coastal salt dome fields exist in different stages of development and perfection. The salt domes of the salines may be regarded as structures that have been not only made, but also partly destroyed. The Damon Mound is a salt dome where the cap rock has developed an unusual thickness and has been pushed

up above the general level of the coastal plain. The usual depth at which the cap rock lies below the surface of the ground in most of the fields is perhaps about 1,000 feet. In the Goose Creek field the cap rock is as yet not as well developed as in some of the other fields of this kind. Here it lies at a depth of 3,500 feet. It has been suggested that the great depth to the cap rock in this field is due to the fact that the salt dome in this case is in an incipient stage of formation. The Goose Creek field would then represent the early stage in the formation of a salt dome structure, and the Damon Mound would represent a very late stage.

While the salt dome oil fields are like other oil fields in that the oil is held in a porous body by an impervious rock, the conditions which obtain in the coastal oil fields are entirely different from those existing in most other fields in all parts of the world. The salt domes are relatively very high and narrow. Their horizontal extent is small. Some of them approximate the proportions of a tree stump rounded at the top and appear as if they had been pushed up through the strata like a huge punch. The strata that have been penetrated are pushed aside and more or less torn, as it were.

The rock that contains the oil on the top of the salt dome has not been found anywhere except in the dome structures. It cannot be classified with any of the strata in the formations penetrated by the dome and it would not at all be surprising, if, when we know more about the history of the salt domes, we should find that the bedrock in different salt domes is made at different times. You will understand then that we cannot in the case of the salt dome structures, speak of the oil-bearing rock as a formation of the Tertiary sediments in which it lies.

You will see from this account of the oil fields of the coast the reason, I think, why geologists have been able to do so little toward the finding of these fields. For the most part, the coast is superficially covered by recent deposits that have been but little affected by the local disturbances by the salt domes. These deposits are of soft sands and clays in which any folding that may exist is entirely concealed superficially. A geologist cannot, as in most other fields, make out the dips of the formations through which the salt domes have been raised. Naturally many of the coastal dome fields have been discovered by accident.

Those who have given most attention to the development of the oil resources in this part of our state look, nevertheless, upon certain physical characteristics as somewhat diagnostic of a buried salt dome. The most conspicuous of these "surface conditions," as we call them, is the existence of a tract of elevated land having a very flat dome-like shape. This, as I have already explained, is the topographic expression of a salt dome where the dome is raised faster than it can be eroded away. Another is the existence of depressions in the surface of the plain, resulting, as it is believed, from solution of the salt causing a settling of the overlying land. Another surface indication is the continuous escape from the ground of gas and oil. There can be no doubt that oil and gas escape to the surface slowly from some of the oil pools in these structures. Some believe that such escape of gas has resulted in places in the formation of small hillocks in the places where gas has escaped for a long time. Springs of water of unusual temperature and of unusual mineral qualities are also believed to issue from some of the salt domes, the supposition being that these are really artesian waters coming from the mineralized ground close to the cap rock. Still another surface indication is the presence in the soil of a material called "paraffin dirt." This is not at all paraffin, but more resembles a precipitate of peaty material, if such a substance may be supposed to ever be produced by nature. When heated this substance gives an odor of peat. It resembles art gum in its color and physical appearance when it contains the moisture usually present in the subsoil of the coast country. It is yellow and elastic when in this condition. When dried it has the hardness, color and firmness of glue. Paraffin in dirt has been found in the soil in a number of the salt dome oil fields and it has been suggested that it may be the result of some reaction between escaping gases and vegetable materials.

Some geologists believe that most of the salt dome fields have already been discovered in this state. I can hardly share in this belief. Our coast country is extensive and the surface indications enumerated are quite indefinite of recognition. With the exception of the mound-like elevations marking some of these fields, none of the surface indications can be distinguished readily. On the supposition that the Goose Creek field is a salt dome in an incipient stage, it seems to me that the chances are good

for finding other oil fields with as poorly marked surface indications as the Goose Creek, in many other places, from the Rio Grande northward. It seems likely that oil fields will be discovered in other places where there are indistinct domes.

Nine-tenths of all the oil fields of the world belong to the kind I have mentioned as holding oil in strata which have been more or less flexed or folded—the third group of oil fields that I enumerated at the beginning. Excepting the Thrall field and our coastal fields in this State and in Louisiana, all the oil fields in the United States, so far known, may, I think, be classified here. In coming to an understanding of oil pools of this kind it is well for us to again recall the fact that nearly all our formations are very, very old; that in the course of time the earth has never been at rest; that it has for long periods been lifted here, sunk there, folded in some places and faulted at others. Most sands and clays were laid down flat and were originally horizontal. But such is not their position today and the time since they were disturbed in their position may be so far back that whole continents and many mountain ranges may have been made from the earth since that time, and very likely as many oil-bearing formations as now exist may have been eroded and washed away from the continents several times. Understanding this, we are prepared to appreciate the great number of different kinds of structures in which oil may at present be entrapped below the surface of the ground in such formations. I need only refer to some. The most common perhaps is the anticline; that is, an upward fold. This may be high or low, the rocks rising from less than ten to more than a thousand feet in a mile on either side toward the crest of the structure. Oil will travel toward the highest humps of the anticline and may be absent in the lower places. Most of the oil fields in Pennsylvanian may be ascribed to structures of this kind. Many occur in the central and western States. Dome-like structures are also known. In one sense domes are merely shortened anticlines. They can hardly be said to be as frequent as anticlines, however. Structural terraces is another class. We have here a structure where rocks, after running up on a dip or slope, will lie flat for some distance, and may then continue to dip as before. In such a flat structure oil is apt to accumulate under the shelf-like level part of the formations. You will per-

ceive that a structure of this kind does not give as good promise as an anticline or dome, for the reason that at one side of the level structure there is no retaining limb. The oil may have escaped by that route.

Another favorable structure is an edge sand. Where the formations dip for many miles in one and the same direction, there is little prospect for oil being found, as it may travel along the under side of the retaining formation and may escape to the surface. We heard in the discussions this forenoon that we have such a condition over the region where we have our best strata for oil fields, but if this represents sand, a sandy layer, and if these papers represent the clay, then we have a condition that we may call edged sand. (Illustrating with papers.) But if in such a structure there should be found a sand which would terminate upward between two clays, it is clear that any oil in this sand would be retained, unless there were some lateral escape in one direction.

In the old mountain structures of the Appalachians, faults have always been avoided by prospectors, and for good reasons. The oil seems to have escaped through the faults, which have acted as open fissures. The Appalachians, as you will remember, are relatively very old mountains, and it is quite likely that although no oil is found in reservoirs that terminate against faults in the Appalachian country at present, by faults we mean places where the ground has been fractured and the rocks moved up and down, it may very well be that at some earlier date the oil was still there. At any rate, it has been found in California that sands cut by faults are sometimes good reservoirs for retaining oil. It may be that the faults in California yet retain the oil on account of their youth. There is not the slightest doubt that the faults in the Appalachian mountains are, as a rule, twenty or thirty times as old as the faults in the coast range in California. Another explanation has, however, been made for this difference. It has been shown that the heavy residue in certain oils in California is effective in sealing up the faults.

The various kinds of structures capable of retaining oil are too numerous to be fully discussed in a brief presentation. The question in which we are especially interested is, what strata contain oil in the sediments in Texas? Perhaps I should mention for

the benefit of some of you that we distinguish between older and later rocks that have been made during the past history of the earth and we speak of the very oldest rocks as the crystalline rocks that underlie everything else, and then we have a series of formations one above the other, of sedimentary rocks. In enumerating the oil bearing formations of Texas I shall begin by mentioning the lowest, the oldest of these rocks. The oldest rocks in which we know of any oil in this state is the Ordovician. In an uplift which covers an area of the size of an average county in the vicinity of Marathon, in Brewster County, these rocks are present over some hundred square miles. Their condition is here unlike that in the central part of the state. They have not been metamorphosed into marble, they are still highly bituminous. It is believed that a well which was bored to the depth of about a thousand feet some years ago obtained a little oil from these Ordovican rocks. The Silurian and the Devonian rocks are practically absent from this state. It is doubtful if we have any Mississippian in Texas.

A formation known as the Bend, named from the Bend postoffice in San Saba County, was described some twenty years ago by Dr. Cummins, whom we have had the pleasure of listening to today. I guess it was nearly thirty years ago when they were described. Up to this time we lack positive proof that the formation is Mississippian. I today spoke to Dr. Moore, from Kansas, who has made quite a study of our fauna of these rocks, and I understood that he is of the same opinion as Professor Cummins, that they belong to the Pennsylvanian age. This is known to lie also on the south side of the uplifted area in Llano and Burnet Counties, and it outcrops in the vicinity of Marble Falls.

This formation dips under the Pennsylvanian to the north and does not rise to the surface again in this state. There can be no doubt that it is continued somewhere under the counties of Brown, Eastland, Palo Pinto, Jack and Montague, up into Oklahoma, and lies within reach under other counties to the east and west of this line. This formation consists largely of black limestone and black shales and it contains some sands also. The whole is strongly bituminous. The basal shale in this formation is seen in San Saba County where it contains a large amount of bituminous material. Until recently it has generally been sup-

posed that the Bend lay too deep for successful exploration by the drill, but during the last two years some borings have been sunk into this formation in Eastland, Stephens, Palo Pinto and other counties, and some highly productive deep oil-bearing sands are now being developed in this formation.

Later rocks of undoubtable Pennsylvanian age underlie a quadrangular area extending from Montague to Lampasas County on the east and from Concho to Wichita County on the west. It is true that these rocks do not come to the surface over this entire area. On the east they are covered by the Comanchean-Cretaceous and on the west by the Permian. But they lie at depths suitable for exploration in a rectangular area some 100 miles wide and some 240 miles long from north to south. In this region we have the same formations that have yielded most of the oil in Oklahoma and Kansas. What are the chances of finding oil in these strata in this state? Already we have several fields developed—at Electra, at Petrolia, near Moran, and near Strawn, with scattered prospects where smaller quantities of oil or gas have been found, in single wells or in several wells, as at Trickham, Mineral Wells, Bangs, Lohn, Santa Anna, and Abilene, and I have no doubt left out some. It may be true that our Pennsylvanian contains less sands than the Pennsylvanian of our neighbor state to the north. Especially as we go west do the sandstones which lie in reach of the drill appear to grow smaller and less frequent. But certainly our Pennsylvanian contains a sufficient number of sandy beds to store a vast quantity of oil. Looking at the structures which are developed in the area and the beds under consideration we find that the general position of the strata in this region is very much like that farther north in Oklahoma and Kansas. The beds have a general dip to the west over most of the region defined. Possibly this general dip is somewhat greater in Texas than further north. In the southern half of the area the average dip seems to be near 30 feet to the mile, being probably greatest fartherest south owing to the uplifts in the Central Mineral Region. You will understand from this that provided there are sands in the Pennsylvanian which terminate in shales to the eastward, there are good chances for oil and gas pools in edge sands. It would be very singular, indeed, if no considerable pools of this

kind were found over so large an area. The region has not been subjected to any great disturbances. The formations as a rule are folded only with extreme gentleness. There are many places where structural terraces exist. Dips to the east in a region of general monoclinal structure to the west will give the right anticlinal structure and all such structures should be tested. Good exposures of the bed rock occur over most of this region and by proper careful examination of these exposures some favorable structures have already been found by the two or three hundred geologists who have been at work in this state. I wish to pay my respects to the persistent and successful work that you have done. This is a region where geological work can be expected to be effective, and no test should be made without the advise of a geologist. The sands of the Cisco and Canyon have already yielded a great deal of oil in the Electra field and some of the sands of the Strawn formation have proved oil-bearing near Strawn and Moran. From some studies which we have recently made in the western part of the state it is probable that some unconformities exist in the Pennsylvanian in the central part of the state, as well as in the west. From some observations that we have made, it does not seem so unlikely that the unconformities will separate the Permian from the Pennsylvanian, but rather that we will find some unconformities in the Pennsylvanian itself and in the Permian, for such are the conditions in the western part of the state. This is a feature which may make the work of field geologists looking for oil, exceptionally difficult. It appears likely that there may be not only one, but possibly two or three unconformities. It seems quite probable that there is an unconformity between the Pennsylvanian and the Permian, and it is quite likely also that other unconformities may exist. The work necessary to solve these structural problems requires not only considerable time in the field, but the most intimate knowledge of fossil forms. The studying of fossils is a work to which oil geologists can give but little time, and it is for that reason, the special function of official surveys maintained by the state and national governments. I regret very much that so little has been done in the way of working up the fauna, the fossils of this state.

The Permian formation which overlies the Pennsylvanian on the west has so far given little promise of oil production. The

lower part of these rocks included in the formations known as the Albany, the Wichita, the Clear Creek, and the Double Mountain consist of shales, limestones, and some sandstones. Nearly everywhere the limestones are bituminous, especially in the lower formations. There seems, however, to be a dearth of porous rocks capable of serving as reservoirs. I was very much impressed with this fact in the study of sections of the Glass Mountains. Going farther and farther west the sandstones play out and the shales are replaced by limestones, frequently changed to dolomites. West of the Pecos, limestones are predominent in the Permian. The number of explorations that have been made in the formations of this age is not as yet very great, and few if any, of them have been scientifically located. For that reason I do not consider the negative force of that evidence as conclusive as it would be otherwise.

Finally, we must not entirely overlook that large area between the Llano and the Marathon uplifts, where the Pennsylvanian and the Permian rocks without any doubt, underlie a cover of from 100 to 1,000 feet, or more, of Comanchean limestones. This has been called the Edwards Plateau, the great limestone country of the southewestern part of Texas. I fully believe that some oil fields will be found on this Plateau. That some structures favorable for the collection of oil in the Pennsylvanian and the Permian sediments underlie this area there can be no doubt. We know that the Marathon uplift extends northeastward beyond its exposures and there can be no doubt that the Llano uplift had brought up the Pennsylvanain rocks to the surface westward and southward before the advance of the Comanchean Sea. This region should be handled carefully. Possibly it may be of some interest to geologists to mention that there the Comanchean sediments have lately been uncovered, the present drainage is consequent to the larger structures; which suggests that anticlinal folds may coincide with the present divides in the drainage.

Leaving the formations of the Paleozoic age we find that these are separated in Texas by a great unconformity from the overlaying Mesozoic formations. In other words, we find that after the Pennsylvanian and Permian had been laid down in the Paleozoic seas, and the greater part of this state was lifted above the waters of the ocean and for a long period sub-

mitted to extensive erosion. As I have already stated in connection with the description of the Thrall field, the entire state was again submeregd at the beginning of the Comanchean period. During this period deposits consisting chiefly of limestones were laid down with a thickness of from perhaps only a few hundred feet, in the northern part of the state, to at least two thousand feet near the Mexican border. The Comanchean limestones are interbedded with some marls. With a single exception, this whole system of rock has so far proved to be barren of oil and gas, the only exception being a small field in the Paluxy sands of the South Bosque, west of Waco. At this place there are some wells from 400 to 500 feet in depth, that yield from ten to twenty barrels of oil per day, or that was the condition when I was in the place about two years ago.

The upper Cretaceous is of a different kind of material. It consists in the main of marls, marly limestones and bituminous clays. The principal oil-bearing horizons in the upper Cretaceous are those from which production has been obtained at Corsicana, Powell, Mexia, and in the Caddo Lake region in the northeastern part of the state. At Corsicana there is a sand in the lower part of the Taylor marl from which production has been obtained for the last twenty years. The oil present in this sand is seldom more than a few feet deep, and many a well has been lost by going too deep into the salt water below the oil. The lowest oil-producing sand in the upper Cretaceous is known as the Woodbine sand. This forms the base of the formation, and it appears to be of about the same age as the Dakota sandstone in the northern part of the United States and Canada, where it also has been found to yield some oil. This is the sand which gives the lower oil in Marion County, in the Caddo Field. The formation is known to underlie the country of northeastern Texas over probably some twenty or thirty counties in a region where the general structure is almost horizontal and where for this reason it would seem that conditions for the retention of pools would be likely to occur. It seems to me that this sand has not received the attention from geologists which it should have. One reason for this, perhaps, is that it lies deep in the eastern part of the state. The irregularity of the sand is likely also to make necessary very careful testing of any holes to be

made. One of the encouraging features of the prospecting of this sand lies in the fact that it is known to be affected by a broad uplift extending in a northwest-southeast direction from Panola to Grayson County. A discouraging feature is the fact that the rocks exposed at the surface do not always represent the deeper structures as in the case where the Cretaceous rocks are overlain by the Tertiary; and the further fact that in this entire region exposures are few and give but little guidance to the geologist in making out local structures. You will perceive that what has been said with regard to the Cretaceous sands in the northeastern part of the state will be true also for a belt extending toward the south and west, following the western boundary of the Tertiary sediments. It may be interesting to note that this belt terminates in Texas in the southern part of Maverick County and that at a point about 22 miles southeast of Eagle Pass two gas wells have been made. In both the gas was found in some sands higher up in the upper Cretaceous formation than either the Eagle Ford or the Woodbine.

I should, perhaps, say a few words with regard to the chances of finding oil or gas in the Eocene Tertiary. This formation extends in a belt from Louisiana to Mexico, southeast of the Cretaceous area. The Tertiary taken together has a thickness of not less than 4,000 feet. It consists of marls and sands and it contains at least two horizons in which lignite beds are frequently found. Over this entire area gas and oil have been observed escaping in a great number of springs and in shallow wells, but so far not a single large oil field has been discovered. The formation as a whole contains considerable bituminous material and there are some geologists who still hope that oil pools may yet be found in the deposits of this age. Our experience so far has been discouraging, except in localities where salt domes exist, as I have already explained. The general structure is a dip to the southeast. One of the reasons why oil may not have accumulated to a greater extent than has yet been found in this formation is its steep dip, which in many places amounts to as much as 50 feet per mile. If this is the cause of the scarcity of oil in the Eocene Tertiary, it would seem that the best chances for finding any pools that may exist is in northeast Texas and in the Rio Grande embayment from Three Rivers to Carrizo Springs.

Very little prospecting for oil or gas has so far been undertaken in that part of the state which lies west of the Pecos River. Most of this country has no lack of favorable structures. In the older structures which affect the Paleozoic rocks in this region it is quite doubtful that any considerable bituminous deposits will be discovered. Sharp folds and faults which have been in existence since the end of the Paleozoic era can not be regarded as promising. But there are structures in other places which have been made since the time the upper Cretaceous was laid down and these must be considered as somewhat more favorable. The areas where the upper Cretaceous deposits still remain are quite limited. They probably do not exceed twenty thousand square miles. It may be of interest to state that some gas was discovered more than thirty years ago in the upper Cretaceous in the Viejo Valley south of Valentine.

In conclusion let me say that I have found it impracticable on this occasion to present more than the merest outline of the oil geology of the state of Texas. Our formations are many and variable. The area of the state is large and geologic structure is complex. All that I have attempted to present to you is a few of the general ideas which may help to acquire the right point of view in approaching the subject of the geologic study of oil and gas. In the detailed knowledge of our formations we are far behind in the state, owing at least in part to the fact that the work provided for by the state has been discontinuous and interrupted. It is my hope that the bureau I represent shall be in a position to undertake such general work as is needed for accurate determination of important stratigraphic horizons, not only by the paleontological method from the study of fossils, but also in the study of underground conditions from well records, and from the examination of cuttings secured from drill holes. In this last kind of work much more might be done, and should be done, while prospecting is general, and while observations can be made on the various formations which are being explored.

EXPLORATIONS IN CHINA

By M. L. Fuller, *Dallas, Texas*

Dr. David White has spoken of the great importance of taking up foreign investigations with a view to locating additional deposits of oil. This has been in the mind of the large companies for many years, and in 1913 an extensive exploration was organized by the Standard Oil Company of New York—not New Jersey—to investigate the oil possibilities in China.

This exploration was placed in charge of my associate, Mr. F. G. Clapp, and myself. We went to China in December of 1913 and stayed until the middle of 1915. In all we had six parties in the field and covered over 25,000 miles of routes in north and western China, including Chihli, parts of Manchuria and Mongolia, Shantung, Shensi, Kanan and Honan. I myself made 8,000 miles on horseback, much of which was in territory never before seen by a geologist.

Now to get the best and simplest idea of the geography and general conditions of Northern China one may compare it, in a way, to the northern United States. In northeastern China, including Chihli and Mongolia, we have sharply folded rocks, comparable to those of New England. On the coast we have a broad coastal plain like the coastal plain in the United States, except that it is wider. Just inside the coastal plain we have a long range of mountains extending hundreds of miles, which we may compare with the Blue Ridge mountains. Then there is a small local basin followed by another range, which we will compare with the Alleghanies. The principal difference between China and the United States is that the second, as well as the first, range in China shows granite along its axis. Inside of this second range of mountains, is a great central basin, which we may liken to our great central or Ohio-Mississippi Basin. Although not as broad as the latter it stretches away as a plateau deeply cut by streams much as the plateau of West Virginia and Ohio is cut by the Ohio river and its tributaries. It is drained by the

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*Given as an illustrated lecture.

great Whang Ho which, however, instead of continuing southward like the Mississippi, breaks through the mountains on the east at a point analogous in situation to that of the Potomac river. West of the great central basin one comes to another great range of mountains which may be likened to the Rockies, beyond which lies Turkestan.

Perhaps the greatest difference superficially between the general system of geology in the United States and China is that in China the rocks are overlain by a great mass of clay material called loess, which varies from 500 to 2,000 feet in thickness

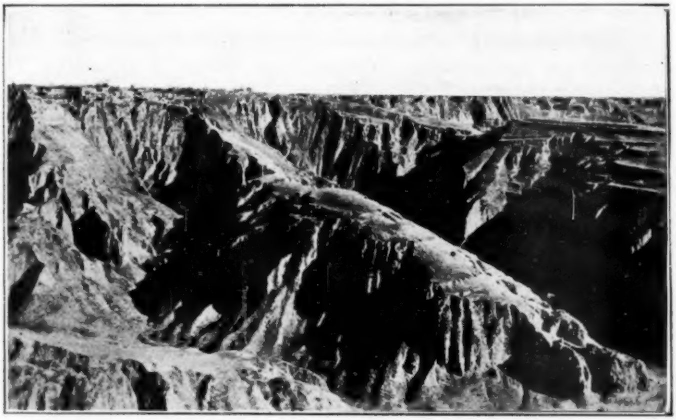

Fig. 1. *Dissected Plateau in Province of Shensi*

according to locality. On the early maps of China, notably those of Richthofen, the mapping of formations was carried only to the Whang Ho, everything west being shown as loess. As a matter of fact, every stream of any consequence cuts through this loess and down into the underlying rocks, making it almost as easy to work the geology as in many parts of the United States.

The formations in China, in the section across what one may call the great basin of Shensi, are shown in Fig. 1. At the base, at the right of the figure is what is called Sinian limestone, of pre-Carboniferous age. Immediately above this and infolded with it is a series usually from 300-1000 feet thick, which we may

call Carboniferous—at least it is a series of shales, coals and thin limestones, similar to the Carboniferous rocks of Pennsylvanian. Above these beds and resting unconformably upon them, is about 2,000 feet of sandstones and red shales called the Fen Ho series also Pennsylvanian or Permian in age. Above these, in turn is the Shensi series of sandstones, some 6,000 feet in thickness extending across the greater part of the Province of Shensi with a dip of about 1-2 degree or 50 feet per mile to the west. In

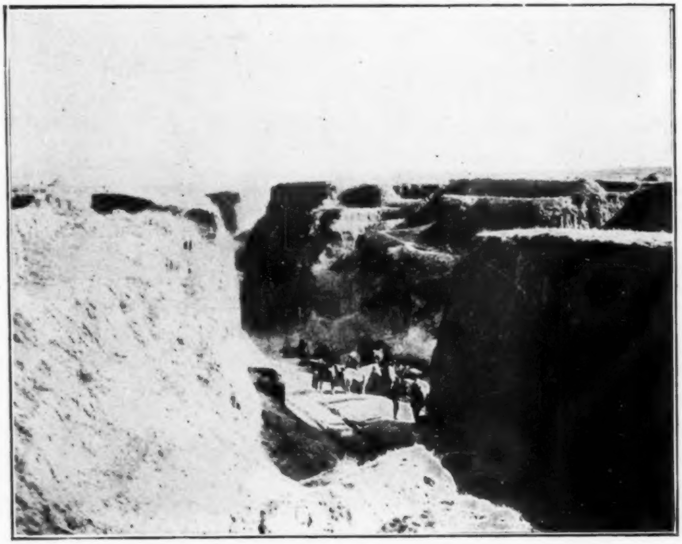

Fig. 2. Loess Road in Shensi

the entire 6,000 feet and in the 100 miles or more in which the series was exposed not a single bed was seen which could be correlated or followed for any distance. There was in one place a shale that could be followed for two or three miles, and farther west a heavy sandstone lense that could be followed for a somewhat greater distance, but, as a rule, key beds or definite markers were entirely lacking.

Over the thick Shensi sandstones is a thin series of red limestones and shales which can be identified over broad areas.

Above this limestone is a thick massive red sandstone (1000 feet) of probably Triassic age. Over this, in turn, is a thousand feet or more of red, gray and green shales continuing across the basin until the beds begin to rise toward the mountains on the west side.

A map of the Province of Shensi shows the formations just described, bending in a southwesterly direction, as those of the Appalachians bend toward the Mississippi.

Fig. 3. Loess Bridge in Shensi

The question will be asked: "How did we travel in China." Our traveling was done on horseback, as a rule, but we had many other methods. Occasionally we rode in wheelbarrows—as you have all perhaps seen the pictures of Chinese wheelbarrows—and I assure you it is not an uncomfortable method of transportation. Occasionally we tried the sedan chair, borne between two mules, but the most uncomfortable method is by the Peking cart, a cart without springs, which shakes one around in a manner one

never forgets. Camels were tried by one of our parties in the Mongolian desert, I myself made one trip down the Whang Ho in a junk.

The next view (Fig. 2) shows one of the roads over which we traveled, a road which probably dates back to the Bible days or even before, and has been traversed continuously for thousands of years. As it is used the wind blows out the dirt and it becomes worn down 25, 50 and even 100 feet in places. These roads are very narrow, so narrow that two carts often cannot pass, except at long intervals. In an attempt to go into the interior in Ford automobiles the carts had to be cleared from the roads for a distance of twenty miles before the machines could proceed.

Fig. 4. Cart and Mule Mired in Road

Fig. 3 illustrates another road through the loess country. All the material from bottom to top is the yellowish-gray silt or clay called loess. In this material the headwaters of the streams often work back toward one another. On the right the stream is cutting back from one direction and on the left it is cutting back from the opposite direction. By virtue of its peculiar attribute of standing with vertical faces the loess has been left as a wall-like dike or bridge 150 or 200 feet high between the heads of the

two streams, while not more than ten feet wide on top. Sometimes the top is only two feet wide, and in one place it was so narrow that the mules actually slipped in crossing.

The next photograph (Fig. 4) shows another example of the road conditions encountered in the loess region. The mule lying half buried in the soft mud was not as nearly dead as he looks, for as soon as he was extricated from the cart and harness he jumped up as lively as ever.

The next view (Fig. 5) is one of the most remarkable road pictures we succeeded in taking. The road is deeply worn in solid

Fig. 5. Road Worn by Cart Traffic

rock, a hard sandstone, over which the carts have been drawn for thousands of years. As it was used, the ruts gradually wore down until the axels dragged on the ground, when a little stone was chipped off the center until they no longer touched. From the size of the horse in the back ground—probably about five feet in height—it appears that this particular road has been worn down by the traffic which has passed over it at least five or six feet into the solid rock.

The following view (Fig. 6) is one of a series showing some of the places in which we passed our nights. It illustrates one of our most common sleeping places, a magistrate's or yamen palace. Now "palace" is very high sounding, but this is a palace

only in name. The interior is shabby and dirty, with dirt or brick floors.

In the great majority of cases, we camped in some place like that shown in the next view (Fig. 7) in which the openings represent the so-called caves, dug back into the loess cliffs for a distance of 30 or 40 feet and with heights of 10 or 12 feet. Walls of adobe-like materials are built across the front in which a door and a place for the smoke to come out are left.

Fig. 6. Entrance to Magistrate's Yarmen, Shensi.

Some of these caves are said to have been in use for hundreds of years. On the top of the ground, above the cave, is an ordinary village, with houses made of wet loess which, when dry, are as solid as the adobe houses of our Mexican border.

The next picture (Fig. 8) is one of a very unusual type of village. The Chinese become so addicted to the cave habit locally that when there is no natural cliff for them to dig into they make one by digging a hole in the ground, usually rectangular in shape and measuring perhaps 50 by 100 feet, with a depth of 25 or

30 feet. On the sides of this excavation they dig their caves in the same manner as they do in the natural cliffs.

This view (Fig. 9) shows another of our stopping places, a rock temple. Inside of some of these caves the sandstone walls are carved with images, some of them quite elaborate. In one of them there are over 5,000 images of Budha carved upon the walls, besides a large central figure left in the center as the rock was taken out.

Fig. 7. Caves Dug in Natural Cliffs.

Sometimes the images in the inside of the caves or temples are of a grotesque type like that of the next view. (Fig. 12.)

You may ask: "Do the Chinese object to having foreigners sleep in their temples?" They do not. It is a common thing—in fact almost universal—for the magistrate to take you to the temple if he has no room at his yamen. We carried our folding beds and we slept among gods or even among coffins. Once I slept on top of one of the latter.

Our sleeping places included many other interesting build-

ings. We slept in commercial clubs, Anti-Footbinding Society houses, Anti-Opium Society rooms, and in police stations. In fact, it is hard to say what we did not sleep in—anything that was capable of covering the party was gladly accepted.

As to eating, we had good, plain American food. We found that American parties traveling in an unknown country make better progress and do better work when carrying their own supplies than when using native food or unappetizing pressed and

Fig. 8. Underground Villages

condensed foods. We carried American canned goods, which we could obtain in China as cheaply and as easily as in the United States. For breakfast we had oatmeal or some other cereal, bacon and eggs and coffee. For lunch we often had what was left over from other meals, because while traveling it was not convenient to stop for a hearty meal. For supper we had soup, one meat course, vegetables, fruit, a little desert and chocolate. It was not necessary to take eggs from America. I bought eggs in China—only five years ago—for one and one-half cents a dozen. I purchased beefsteak for six cents a pound, mutton for three

cents a pound. More than once I acquired a whole chicken for twelve cents. These were the prices that prevailed when we went into the interior. But they didn't remain long at that level. We created an unusual demand that soon ran the prices up.

The result of our system of provisioning was fully justified. It cost a little more money than would have been the case had we used native food but it was not very expensive to carry American food with us. Probably about sixty cents a day would

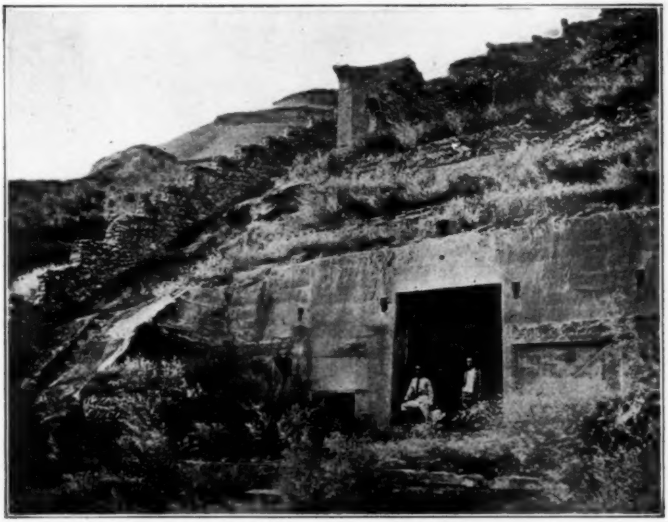

Fig. 9. Entrance to Rock Temple, Shensi

cover the cost of the food and forty cents a day the cost of transporting it by mule, with perhaps an additional cost of twenty-five cents for incidentals, or a maximum of about $1.25 a day per person.

In the six parties that went into China, spending from six to eighteen months in the field, there was not a single day lost on account of sickness, I think that is a record that few expeditions can equal, and I attribute it largely to proper food and proper system of running the work. The latter was never forced,

yet we covered as great a distance as our mules could carry our equipment. All water was boiled. In fact, few Chinese drink water in the raw state, tea being a nearly universal beverage. The Chinese are creatures of habit, and once one starts them on the right path they will stick to it. They inherit the boiling habit,

Fig. 12. Temple Image

hence we had no trouble in getting them to attend to it for us. We used porcelain filters as an additional precaution. Occasionally we drank water from springs without boiling but we could never teach our servants the difference between water from a spring and that from a dirty well, hence we never drank unboiled water except when we got it ourselves.

As we traveled through the country we kept a complete map

and records of our routes. Directions were secured by compass sights, taken to nearest 5 degrees from horseback while in motion. Instead of measuring distances, we obtained them by recording the time travelled, after determining the horse's rate of progress by a cyclometer attached to a bicycle wheel pushed by a Chinaman. It may seem that by using sights taken only to the nearest 5 degrees and by timing rather than measuring distances, a considerable element of error would be introduced, but in actual practice the error proved to be negligible. A day's circuit of thirty miles might not, it is true close within a mile or a mile and a quarter, but the closure at the end of a week or at the end of a month would usually be nearly as close, since the longer the circuit the more nearly compensating were the errors. When dealing with a province as large as one of our states the errors when distributed scarcely show on the map.

For rapid reconnaissance mapping no other method which I have seen tried is as quick and as accurate as the one described. We sketch the roads, put on all villages, temples and other identifying points, all streams and hills, all turning points, and sufficient elevations for the drawing of 50-foot contours. All this was done while the horse was in motion. Under ordinary conditions of travel no stops were made for sketching or note taking. The method required the spending of some two hours for expanding, revising and inking one's notes at night, which come hard after ten hours in the saddle, but the results justified it. We could map as many miles in a day as our mules could carry our equipment, and we did it day after day, month after month. We did not work on Sundays, except when rain held us up during the week. It was found that both horses and men could do more in the end in a week of six days than in a week of seven days, provided one traveled every day.

The next series of views shows some of our difficulties in getting the rigs and equipment to the locations at which the wells were to be drilled, often several hundred miles from the nearest point on the railroad. In Shensi, where the tests were made, there is only one road leading to the oil district. On this carts were used, but elsewhere everything is carried on mules. To haul the rigs and casing required a thousand mules and nearly as many men. Thirteen pairs of mules were required, I believe, to haul the

boiler over the worst part of the road. The road often sloped outward toward the ravines and to keep the wagon with the boiler from overturning a cable was attached to the top with about twenty-five coolies pulling at the other end. Even with these precautions, accidents sometimes happened, as seen in the view (Fig. 10) which shows the overturned boiler. The passage of the Wei Ho, one of the branches of the Whang Ho, which had to be crossed, was made on scows thirty-five or forty feet long and half as broad. On one of these as many as twenty-five or thirty mules with nearly as many men could be carried on a single

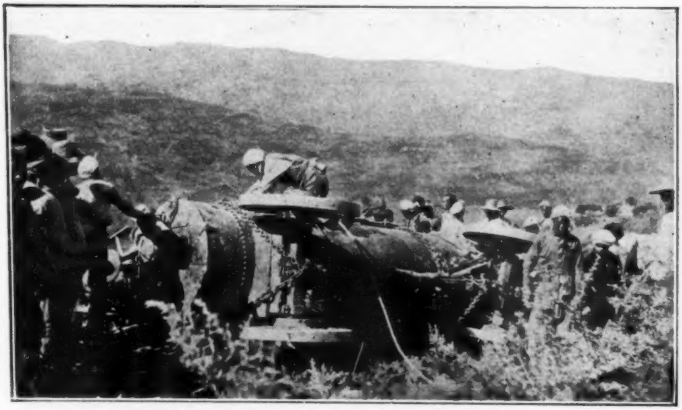

Fig. 10. Overturned Boiler.

trip. The river, though in places a mile or more wide, was only a few feet deep permitting the use of poles as a motive power. (Fig. 11.)

The next view (Fig. 13) shows the carts loaded with sections of casing as they appeared standing in the yard of a typical Chinese inn. The floors are generally of dirt, though occasionally of brick, and usually the rooms are without chairs. There is always a raised platform about 2 1-2 feet above the ground, known as a kong under which a fire can be built in winter. As a rule we set up our folding cots on top of this. The windows, if there are any, are always paper, and the first thing one does on arriving is to patch the paper. This has to be done every time

for the reason that before a guest leaves the paper is usually full of holes made by inqusitive natives who, in order to peep at the occupants, wet their fingers and punch them through the paper. If they stuck them through without wetting it would make a noise which would attract the occupant's attention. The peeping continues until a well directed biscuit, teacup or other handy article drives the observer away. The doors of the inns, when they have them, are of wood. I have been in a city where there

Fig. 11. *Transporting Men and Mules Across the Whang Ho.*

was not a door on its hinges in the entire city, every one of them having been taken by the native soldiers for use as beds. A native of this class never sleeps on a soft bed, and a door laid across a couple of saw horses is the equivalent of a downy couch for him.

The next view (Fig. 14) shows the equipment for one well drawn up at a place called Tien Tou, several hundred miles from the railroad. The flat rocks of the lower part of the hills are clearly visible, but above them, not shown in the view, are many hundreds of feet of loess..

Fig. 15 is of the standard type of well rigs used in the testing. Six holes were put down in all varying from 2,600 to 3,500 feet in depth. The first well required three or four months for drilling, but later when it was found that very little casing was necessary, they were put down in about a month.

I venture to say that any party going into China is bound to have some interesting experiences, and we were no exception. The great topic of interest the first days, when we were traveling through northern China and the edge of Mongolia, was bandits, and a few heads on the city gates gave reality to their presence.

Fig. 13. Carts Loaded with Casing

The danger was impressed on us when we started and we were given an escort of forty soldiers. This small army gave us a feeling of importance, if not confidence. We thought the officials who furnished them were very liberal until we found that they were receiving for themselves the allowance and salaries paid by the government to the soldiers while absent with us and in our pay.

We soon found that where the bandits were supposed to be thickest there were none to be seen. They were always at some other place. When we got to the latter they would always be farther on. We never did get to the bandits in northern China. Gradually our corps of soldiers was cut down from forty to

four and those four were used for errand boys and not for protection. If anything had happened, I think they would have run, but they made excellent deputies for dealing with the local officials attending to the red tape which the work involved, as well as giving an official standing to the expedition.

Our real experience with bandits came toward the close of the work. I was coming in on the railroad on a third trip into Shensi, but found on arrival at a certain place that the track was washed out. A Belgian engineer kindly offered me his handcar and with him I started out for my destination. We had gone

Fig. 14. Equipment at Well Location in Shensi

only a few miles when I noticed a large number of natives along the track—Chinese are always along the track—and I thought nothing of it. When we got up even with them they commenced waving their arms, but we just said "Hello, boys," and went on through. When we had gone a little ways I asked who they were and my associate said, "They are the White Wolf bandits." It was all over before one knew there had been any danger. This particular band were the remnants of an army once comprising over 5,000 bandits, which had ravaged Honan, Shensi, and other provinces for over a year, taking city after city in spite of their walls—as thick and high as those of medieaval Europe. If there was no resistance the bandits contented themselves with the

burning of the magistrate's yamen and plundering the inhabitants, but if opposed, man, woman and child was massacred. On the wall of one city I saw notches worn in the stone to depths of 1-2 to 3-4 inch by the ropes by which people were lowered over the edge in their attempt to escape.

On one occasion an associate ran into a band of 180 bandits. Seeing his loaded mules the bandits stopped him and asked him what he had. "Only foreign chow" was the reply. "Let us see it," they demanded. "I can't stop, I'm in a hurry," was his answer as he went on. The bandits made no attempt to interfere,

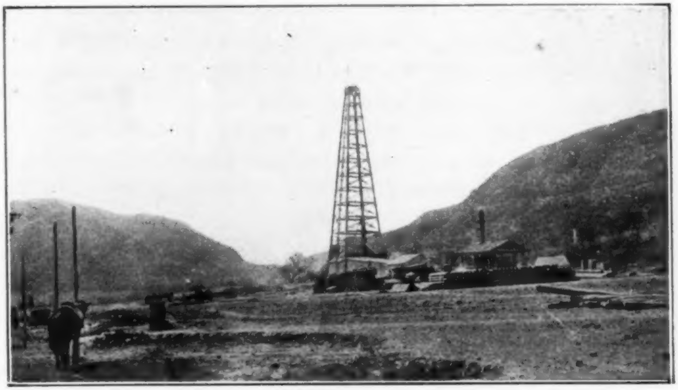

Fig. 15. *Erected Rig*

in fact, this is the general rule when foreigners are concerned. One of our party, Frank Herald, was finally forced to flee with his wife when the city in which they were living was attacked, leaving his horses and some $1,500 in Chinese silver behind. A few guns in the hands of Americans, however, is usually ample for protection. The bandits were around the camp of the drillers on many occasions but never offered any molestation.

Voice: "Did you find any traces of oil?"

Mr. Fuller: "That is a very pertinent question, but I do not feel free to go into particulars. I may say, that we found 63 oil seepages. None of the wells, however, afforded enough oil to be considered profitable, considering their distance from trans-

portation. The reason, as I see it, for the failure to secure more encouraging results is the great thickness of the sandstone series, some 6,000 feet through which the oil seems to be disseminated rather than seggregated in pools. If shales were present to afford barriers, the prospects would be improved. On the east edge of the basin the folding is very sharp with dips up to 45 degrees, but the rocks flatten suddenly with little transition, to a general monocline with outlying folds analagous to the broad low arches which have afforded the oil in the Appalachian fields of this country. The absence of key beds made it necessary to work from dips alone and structural contouring was impossible. In the more promising areas plane-tables were extensively used and every attempt made to discover local structures. Nothing but minor warpings could however, be detected."

NOTES ON THE STRUCTURES AND OIL SHOWINGS IN THE RED BEDS OF COKE COUNTY, TEXAS.*

By J. W. Beede, *Austin, Texas*

There is a very unusual occurrence in Coke County, in the Red Beds of the Permian, in the Double Mountain stage There are a number of very extensive showings of oil and a few peculiar structures. I would call your attention to the general map of Coke County, thus giving some idea of the formations and dip of the beds. The dip is nearly east of north. Beginning at Robert Lee, there are a series of oil showings in a line nearly at right angles to the strike, and best shown on Pecan Creek but also shown in some other places. Here, too, are some little faults, some larger than others, and it is to these I wish to call your attention.

The rocks containing the oil belong to two formations, the San Angelo and another, as yet uncorrelated, lying above the San Angelo, both of which belong to the Double Mountain Stage. The San Angelo beds as exposed in the southeast corner of Coke County are from 125 to 150 feet thick, but you can not get an exposure of the entire thickness, they are largely composed of conglomerate which is quite coarse, the pebbles of which are almost wholly siliceous, all less resistant rocks having been destroyed in the process of transportation. Even the large masses of quartz are completely rounded. Intercolated in these conglomerates are lenticular beds of sandstone and shale. Toward the northwest this coarse conglomerate gives way to finer conglomerates and sandstones of buffish hue. Farther up the Colorado River these beds are of finer texture, and wedges of shales set in and thicken up between the sandstones and the conglomerates disappear except for very local sheets of pebbles in some of the beds.

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This change is accompanied by the sandstones breaking up into what appear to be lenses, but which prove to be crooked channels in a delta filled with crossbedded sandstone. The thickening of the shale beds materially thickens the formation until at Robert Lee it is over 400 feet thick and the driller's log of the Stroud well, four miles west of Robert Lee, seems to show 500 feet of it. In the vicinity of Robert Lee thin sheets of gray dolomite, or anhydrite as encountered by the drill, appear in pairs, the individual beds ranging in thickness from a fraction of an inch to six inches. Two thin beds of selenite were noted in one section. That is the only rock that we would call really related to a limestone or anything of that sort in these beds, and there are no traces of fossils in them. Thus from Tennyson to Robert Lee we have what is probably an alluvial fan, changing into typical very shallow water delta deposit containing thin sheets of dolomites and anhydrite. Two thin beds of foliated selenite were found. The sandstones are highly crossbedded and the showings of oil near Robert Lee occur in these old sandstone channeds, or what appear to be lenses. Some of the lower beds are oil bearing, as shown in wells south of Robert Lee.

Over the top of these poorly stratified beds occur evenly bedded, very fine grained red sandstones and red shales filled with very fine sand, and gypsum beds of considerable thickness. The sand is cemented, if cemented at all, with clay. It is sand in the clay, or clay in the sands, and it is hard to tell which you are dealing with at any time. In the sandstones of these beds on Pecan Creek occurs one of the prominent oil showings of the region. These beds contrast sharply with the underlying beds, in that they are very evenly stratified, and we have in these beds on Pecan Creek, which is twelve miles west of Robert Lee, the westernmost showing of oil. There is a strong showing of oil there.

So far as we have checked them, all of these showings are on or adjacent to mild structures of some anticlinal type common to the region as a whole, and so far as the surface is concerned these oil showings seem to be a type common to the region as a whole, Runnels and Coke County combined.

However, there are other structures occurring in the region of the oil showings which have attracted some attention. These may

be classed under two heads: faults, and crushed zones accompanied by some vertical displacement of the walls of the zones.

A few well defined faults occur, some of the normal and some of the reverse type. In the best case of normal faulting noted, the fault is vertical and open, the upper part being filled with sand, clay and pieces of sandstone, the middle part of the exposed fault containing an eight-inch sandstone dike, the fault being closed at the creek bed at the base of the exposure. The throw of the fault is over 30 feet. There were a number of smaller faults on one side of the main fault, and one on the other side, that, combined, would make a total vertical displacement of over 42 feet. Inasmuch as none of the beds of the main fault match, the total displacement is greater than that given and properly amounts to 50 feet. The other examples of typical faulting are quite small. All faults are in the same direction.

Below this fault on Pecan Creek is another of the reversed type with the rocks of the bluff displaced about four feet. The plane of the fault is about 45 degrees, or a little less than 45 degrees, from horizontal, and then right near this fault there is a case of overturned folding and crumpling in the shales between standstone beds. In other regions there were a number of others observed, but these were without displacement deeper down.

The most common type of structure involving faulting is what might be termed crushed zones. This rock is very soft, and very fragile. In these zones the rocks are crushed and jammed through a zone ten to thirty feet or more in width, with very slight displacement of the walls at the sides. Frequently these crushed blocks have fallen below the level of the corresponding beds in the walls on either side. All of these structures pass into the rock below the bedrock of the creek. (The creeks and rivers are all running in bedrock, and these structures go on down through.)

In the case of the normal faults and crushed zones the rocks are leached from a dark red to light buff for a considerable distance on either side of the disturbance. This is not true of the reversed faults.

All of the dislocations mentioned are smoothly eroded off

on top and the gravels of the late Teritary or early Pleistocene Age here, as it may do, an arm of this structure could well corre-almost as smooth as the floor, before these conglomerates were laid down. In no case is there the slighest disturbance of conglomerates or difference in surface elevation on the two sides of the faults, nor do the open faults contain any of the conglomerate.

From this evidence it is clear that the disturbances took place and the surface was eroded to the present condition of that slope, before the deposition of the conglomerates. These conglomerates are found at elevations considerably over 150 feet above the present river level, and it is probable the age of the structures date back to the latter part of the Tertiary period.

There are two ways in which these structures may have been brought about. First, and most apparent at first sight, is by the solution of rather deep-seated salt beds below the surface. There are none of these structures that could not be accounted for by the removal of 75 feet of salt from underlying beds, if you wish to assume it was there.

A number of the crushed zones are almost precisely what would be expected under such circumstances, except that the displacement is altogether too small compared with the displacement of the largest fault. Again, the remainder of the beds are not sufficiently disturbed, since this material must have been all removed at the time of origin of the structures or later movements of the beds wouid certainly have been recorded. That is, if a bed of salt 75 feet thick had been dissolved out, it must have been all dissolved. Otherwise it would have been dissolved later, it would have been dissolving out ever since, and these structures would have been formed at later times, which, as we have observed, has not been the case.

Furthermore, we would naturally expect salt beds to be dissolved out in a line parallel with the outcrop, rather than nearly normal to it, as it is in the case in hand. However, this statement must be modified since the rocks of much of the region are covered, but over the large area of bare red beds studied nowhere else have these conditions been observed. Further work there may reveal some of them.

Another thing that should be noted is that the occur-

rence of the largest normal fault does not change the dip of the beds on either side of it. That is, the beds do not show the haphazard tilting produced by the removal of thick beds beneath them so characteristic of such conditions. That is, the beds come right up and go right over at about the same dip, at the same angle on each side, so it is not just a local displacement.

Second—the origin of the structures may be deep seated. That is, that beneath an unconformity the slight movement of a fault zone or other structure may have been such as to produce the results noted. Indeed, in case the cause is referred to solution of underlying salt beds, a disturbance of this kind may have facilitated the process of fracturing the beds near the surface, permitting freer circulation of the ground waters and freer diffusion of the salt dissolved.

In case the mountain structure of the lower Pennsylvanian beds of the Marathon region passed northward somewhat west of here, as it may do, an arm of this structure could well correspond to the zone of oil showings and structure shown in Central Coke County. However, this is pure speculation at present—oil speculation at that.

These structures can hardly be fully considered unless the associated oil showings are taken into account.

These oil showing are unique in all the Red Beds that have ever come under our observation. The showings are copious and extensive, and oil in the beds has been found wherever they have been penetrated in the immediate region. By using wood to heat the stones, you can build a bonfire of these stones readily.

The oil may have had three possible sources.

1. Indigenous to the beds in which they occur;

2. They may have arrived by lateral migration; and

3. They may have arrived by vertical migration in the structures observed.

So far as we are aware all the known oil in the Red Beds, except in the Toyah region, is either in a region of known faults as in the Healdton field, or overlies highly inclined bituminous beds beneath the unconformity between the Permian and Pennsylvanian rock, as is the case in the other West Oklahoma fields, from which the oil might have migrated, or the Red Beds overlie highly inclined Pennsylvanian rocks known to be fault-cut,

which places them under suspicious circumstances. In the case of the Toyah field it should be noted that here the Red Beds overlie other beds which very near by are cut by faults of hundreds of thousands of feet of throw and minor faults should be expected there.

If these premises are true and we can place any reliance in the probable origin of the beds in which the Coke County showings occur—that is, almost alluvial deposits from old river beds, with associated gypsum and salt seeps from beds where it occurs—its origin in these beds seems extremely doubtful and should only be assumed as a last resort.

Second, if it is a product of lateral migration, the question of the place that it came from is of even as great interest. To be sure, it is possible to imagine conditions farther west where it could have had a more likely origin, but here, as yet, the drill has given us no information. If we assume faults of larger size farther west this evidence is as yet wanting.

Third, it may have come up through the structures now seen in the region. But these structures are slight and their depth is unknown. On this point the driller of the Robert Lee Oil Company's Stroud well No. 1 reported all the hard rock encountered to a depth of a thousand feet or more as "broken" or reported as "concrete." I haven't seen those samples to verify that. This is the only evidence available and may be taken with as much or as little reservation as the individual desires. If it is true, it would demonstrate that at least some of the structures are deep seated and offer a probable solution of the question.

At any rate, the coincidence of the oil showings in the same local region in which the structures occur may be regarded as a "suspicious association."

Summarizing:

1. The larger structures seem to be those common to the region as a whole. This statement will have to be modified, due to information from W. P. Bentley that in the Stroud well No. 1 they found 150 feet of limestone very much higher than it occurred in any other well; in fact, the old well which was over 1,200 feet, didn't hit it, and they hit it 130 feet higher than the base of the oil well. It would seem that there is an eastern dip of 130 feet, in four miles something like 30 or 40 feet to the

mile or a fault to that extent, and it also shows that these later beds have covered up that structure, so that it is not observable except in a minute degree at the surface.

2. There are none of the faulted structures which could not be accounted for by assuming thick beds of salt at a depth of 350 to 500 feet being dissolved away from beneath them.

3. The age of these structures and the evenness of the beds between them are not in harmony with this idea.

4. The structures may be deep seated.

5. The oil may be indigenous, but this seems quite improbable.

6. The oil may have reached the area by lateral migration, which seems but a little less improbable.

7. The oil may have arisen through the structures noted, which cannot now be demonstrated.

OBSERVATIONS ON TWO DEEP BORINGS NEAR THE BALCONES FAULTS

By J. A. Udden, *Austin, Texas*

The Balcones Escarpment is a prominent geological structure in the State of Texas. It forms the dividing line between the Gulf Coastal Plain and the Uplands of the interior. It is a line, or rather a belt, separating a segment of the earth which has settled relative to another segment on the west and north. This is, at any rate, what has happened in Post-Cretaceous times in this belt. The movements have been not only sufficiently extensive, but they must also have reached to great depths. In Travis, Williamson, Uvalde, McKinney and Medina counties the motion was accompanied with extrusions and intrusions of igneous material into and through the Cretaceous sediments. These volcanics have had a deep source. The relative motion between the two great blocks was comparatively small in the north part of the state. From the Red River nearly down to Waco, the Balcones Escarpment is represented essentially by a gentle flexure to the east. North of the Brazos River, the dip along the line of the Balcones Escarpment only slightly exceeds the general dip of the region farther southeast. Southward from the Brazos River, the motion has resulted in actual faulting which affects a belt at least ten miles wide. Similar conditions exist from Austin to San Marcos and continue through Comal and Guadalupe counties. In these two counties the faults gradually turn more and more to the westward. They continue through Medina and Uvalde counties and extend into McKinney county. In the three latter counties a part of the motion between the two large blocks has evidently been taken up by dips. The displacement is greatest in Travis and in Hayes counties, where it amounts to as much as a thousand feet, if not more. Westward from Comal County the displacement again diminishes and on the Rio Grande we have about the same conditions as on the Trinity. The displacement apparently is all taken

up by a general dip extending for a distance of nearly a hundred miles along the river.

For a more complete description of the Balcones Escarpment I must refer you to the accounts given by Professor R. T. Hill. Very little has been added to our knowledge of this fault zone by recent writers.

The movements and other disturbances mentioned above have evidently all taken place in Post-Cretaceous times. But there is also evidence that volcanic activities were in progress here during the Upper Cretaceous. Extrusives are known to occur interbedded in the sediments of the Upper Cretaceous age in the vicinity of Austin and in the Thrall oil field. Tectonic movements no doubt were attendant on these volcanic activities and were hence already in progress during the Upper Cretaceous age. Recently I have found some evidence that the history of the Balcones Escarpment extends still farther back in geological history and it is this evidence that I wish to present here.

In 1914 the city of Georgetown was boring a well close to the station on the I. & G. N. Railroad. After the drill had gone down to nearly 1,800 feet a number of cuttings were submitted to me for the purpose of my advising whether it would be worth the while to drill still deeper to find a sufficient supply of water. Some water had been obtained at a depth of about 1,100 feet; this rose to within sixty feet of the curb of the well. At 1,200 feet some more water was obtained, but drilling was continued in the expectation of securing a still better supply. On examination of the samples it was found that undoubted Comanchean strata extended down to a depth of 980 feet below the surface. Below this depth the drill penetrated what appears to have been continuous limestone from ---- to ---- feet. From the twenty lowermost feet of this limestone six samples had been taken. These consisted mostly of dolomite containing some fine sand and some greenish yellow material; much of it was traversed by small fissures and a few cuttings were seen to be brecciated and some of the rock was filled with nodular infiltrated quartz. Some sponge spicules were present in this rock. The rock represented in these samples was entirely different from the Comanchean. Below this the driller's log reported red

mud down to 1,280 feet below the surface, a distance of 224 feet. Three samples of this material were represented by variegated soft shale or clay. On being washed this material yielded more or less indurated pieces of reddish-brown shale cut by thin veins of quartz that mostly extended vertically to the lamination of the shale, and were very straight. A considerable quantity of quartz derived from such samples could be washed out and the material recovered. In one fragment of the shale, an inch in length, it was seen that the material represented highly fissured ancient looking shale, that might be described as incipiently metamorphic. It was impossible, however, to determine whether these pieces of indurated shale occurred in all of the red mud as a part of the mud itself or whether some of these pieces might have come from pebbles, occurring in sandy layers in the red mud.

The samples coming from a depth of 1,280 feet consisted entirely of red shale or slate of this kind. It was of very fine texture and decidedly more indurated than Pennsylvanian shales usually are in central Texas. Some pieces appeared more like schist than shale. A sample from 1,340 feet was dark gray indurated, micaceous, slaty shale. Another sample from 1,473 feet below the surface was dark gray in color and still another taken somewhere between 1,300 and 1,800 feet was a black schistose shale. In all there were six samples taken between 1,250 and 1,820 feet and these may be described as highly fissured material bordering between shale and schist and cut by small straight veins of quartz and also by slickensides. Micaceous material was present in very fine scales. Another characteristic of this rock is that on heating in the closed tube it invariably gives strong fumes of ammonia. As it is quite unlike anything known in the Pennsylvanian in the central part of the state it was closely examined for microscopic organic remains but not a trace could be found.

Though I promptly advised against further drilling for water in this boring, I felt somewhat uncertain whether the lower 800 feet in this section might be pre-Paleozoic in age, or whether they were early Pennsylvanian sediments incipiently metamorphosed by tectonic movements affecting older rocks

along the Balcones Faults. From the looks of the cuttings I expected that they would turn out to be pre-Paleozoic.

A year later I received from Mr. Alexander Deussen a set of samples of cuttings from a deep boring near Leon Springs, in Bexar County. This boring was made several years ago. It is located near the rifle range at Camp Stanley, close to the Salado Creek, at a point a little less than two miles northeast from the Leon Springs station on the San Antonio and Aransas Pass Railroad.

The depth of this boring is 2,500 feet. It starts in the Glen Rose, and the Comanchean evidently extends down to 1,015 feet below the surface. At this depth there is a change to brown clay and slaty material, which further down turns to a dove-gray color, and to black. This was penetrated for nearly 1,500 feet. It resembles the ancient rock penetrated in the boring at Georgetown in every respect. It is cut by thin and straight quartz veins. It is in places slightly micaceous. Some of the fragments are in an incipient stage of metamorphoism. Here, as at Georgetown, ammonia fumes were given off on heating the cuttings in a closed tube. A persistent search was made in all of the samples to find some trace of organic remains, but none could be detected. When heated in the oxygen flame no change was noted in the color. In fragments taken at from 1,244 to 1,305 feet, there was evidence of small but marked crumpling and faulting. Some siliceous material, evidently of secondary origin, was noted. The black color present in some of the shale is evidently not due to the corbonaceous or bituminous material, for it is not changed by prolonged ignition in the oxygen flame.

Two analyses were made to determine the approximate chemical composition of this rock in the Leon Springs boring. One of these (1) was from the sample taken at a depth of from 1,045 to 1,077 feet, and the other (2) was taken at a depth of from 1,184 to 2,244. These analyses are as follows:

	(1) Per Cent	(2) Per Cent
Silica	60.50	63.80
Alumina	19.42	18.01
Ferric oxide	8.92	7.43
Lime	1.04	0.83

Magnesia	1.19	2.82
Sulphuric acid	1.94	0.60
Water	5.20	4.66
Potash	2.16	2.02
	100.37	100.17

The material from the Georgetown well and that from the boring at Leon Springs resembles each other so completely that there is no doubt left in my mind of their essential identity. Of all rocks I have seen in this state, the red and the black shales in the Millican formation northwest of Van Horn, in the Trans-Pecos region, resemble them most. On the basis of the similarity of these cuttings to the formations mentioned, it would still seem somewhat hazardous to correlate the two. If the Pennsylvanian should underlie the Balcones Escarpment fault lines, and if it should have been submitted to some considerable metamorphosim, it might perhaps resemble to some extent the cuttings I have described. But the Pennsylvanian would hardly have the thickness or the uniformity of the beds exhibited in the boring at Leon Springs. On such an hypothesis it would still be difficult to account for the presence of the overlying dolomite in the Georgetown boring. Fortunately, the cuttings from the Leon Springs boring give us some information on the nature of the basal conglomerate of the Comanchean. This leaves, as it appears to me, but little choice as between the two hypothesis indicated. A sufficient number of pebbles of this conglomerate were present in one sample to afford an opportunity to make out the nature of the ancient land invaded by the Comanchean sea at this place. It contains about 65 per cent of flint pebbles, 12 per cent of pebbles consisting of a greenish sandstone that I believe has come from the Hickory Sandstone of the Cambrian exposed in the Llano Uplift. There is only one per cent of limestone pebbles and the 22 per cent remaining consist of quartz, micaceous shale and schist, marble, quartzite, and slate. The presence of so large an amount of pre-Cambrian and Cambrian material in the basal conglomerate of the Comanchean proves conclusively, it seems to me, that these formations were extensively exposed in the immediate vicinity of this locality when the Comanchean Sea was advancing. The

Cambrian sandstone pebbles are quite soft, as is much of this sandstone today, and cannot have been transported any great distance. If we take it for granted that the Hickory sandstone was exposed near this point on the shore of the advancing sea, it seems to me that it almost necessarily follows that an uplift which would bring this formation to the surface on the Comanchean land would in all probability have resulted in the bringing up of pre-Cambrian sediments also. The sandstone pebbles are not at all affected by metamorphism and certainly if Cambrian rocks were not worse affected at the time, we can presume that the Ordovician and Pennsylvanian rocks would not be sufficiently altered to resemble the dolomite overlying the schist-like shale in the Georgetown boring.

To my mind the existence of what I regard as pre-Cambrian material to a thickness of several hundred feet at Georgetown and at Leon Springs, both of which points lie in the belt of the Balcones Escarpment, proves that this belt coincides with an earlier uplift of considerable dimensions, most likely following the direction of the Balcones Faults. Going from Georgetown westward we find the Cambrian, the Ordovician and the Anthracolitic all underlying the Comanchean in the vicinity of Burnet, indicating that the Llano Uplift and the Balcones Escarpment are separated by a syncline or a monocline. Going from Leon Springs northward, we find the same conditions again in Gillespie County, and even as far east as in Blanco County. We know then that along the line of the Balcones Escarpment the Anthracolitic and these earlier rocks present were elevated for a sufficiently long period to be eroded practically to a plain, before the Comanchean Sea advanced. With our present knowledge it is, however, impossible to say whether the culmination of this disturbance occurred in the early Paleozoic or in the middle Mesozoic. Judging by the history of the tectonics of other structures, it appears most probable that the deformation in the Balcones Escarpment belt began in the Paleozoic, culminated at the end of the Paleozoic, and continued into the Tertiary age.

Chairman: I wish to ask Dr. Udden as to where he thinks that syncline is with respect to the fault. You say you think

that represents the axis of an old mountain chain, and that there was a probability of a syncline to the west.

Dr. Udden: Yes. I mean if there has been an axis of uplift along that fault, as I think likely from this, then west of there we must expect that there is a dip to the west for some distance—(indicating on map)—from here there will be a dip in this direction, and from here we know that there is a dip to the east. Consequently we know of a dip to the west on the east side and a dip to the east on the west side, which would give us a syncline.

Chairman: You have reference more particularly to the territory north of the Llano Uplift?

Dr. Udden: Yes. I can say that.

Chairman: For the benefit of those who are not familiar with the Balcones Faults, we might state, that the fault extends from Rockwell County, southeast of Dallas, in this direction, down to Del Rio, and it is along this fault line, particularly near Georgetown and Austin and in Bexar County below San Antonio, that these cuttings refer to.

Mr. Cullen: I would like to ask how close to the fault line these wells were.

Dr. Udden: I don't know that I can answer that exactly. With regard to the well at Georgetown I can. I know that there is a fault within a quarter of a mile. One of the fault lines is within a quarter of a mile of the boring. This well was right at the depot. With regard to the Leon Springs well, perhaps you can tell, Mr. President.

Chairman: The Leon Springs well is just about half a mile north of the main fault.

Mr. Hill: I want to say we find somewhat of a confirmation of Dr. Udden's syncline indicated in the Cisco-Burnet Folio by the Geological Survey. Any one who will take that and study some of the dips there of the Smithwick and the dips of the Bend Series to the east will find some fault lines and some very interesting structures that will bear out Dr. Udden's syncline by the ridge along the faults and in the main Burnet Uplift.

Chairman: Dr. Udden, is it your idea that that mountain uplift you spoke of was in Bend times?

Dr. Udden: I don't see how any one can really tell. In the paper that I have presented I stated that in my opinion the maximum in the history of that uplift must have occurred during the Anthracolitic, including the Permian, and I question whether it is possible to place it any more definitely.

PRELIMINARY PAPER ON THE STRATIGRAPHY OF THE PENNSYLVANIAN FORMATIONS OF NORTH-CENTRAL TEXAS.

By FREDERICK BYRON PLUMMER, *Mineral Wells, Texas*

Introduction

The Pennsylvanian area of north-central Texas may be described in reference to the sedimentary formations of the Mid-Continent as two great inliers of Carboniferous sediments that protrude through Cretaceous strata on the east and dip beneath Permian rocks on the west and north. The two areas are separated by a narrow tongue of Trinity sand, and the southmost outcrop butts against Ordovician rocks for a short distance along the Llano uplift so that the southern portion does not truly possess the relationships of an inlier. The shape and exact location of these Pennsylvanian areas are shown on the map (Fig. 1). The total area where the rocks are exposed is approximately 7,000 square miles.

The strata of this Texas area furnish a complete and beautifully exposed section, exceedingly variable in its lithologic character, and very prolific in well-preserved fossils. Yet, because of its isolation from the classic Mississippi Valley section the north Texas inlier has come to be one of the last portions of the Pennsylvanian on our geologic map to be differentiated or indefinitely correlated with other well-described areas. Now, due to the discovery of its great petroleum resources, no other area is receiving so much attention.

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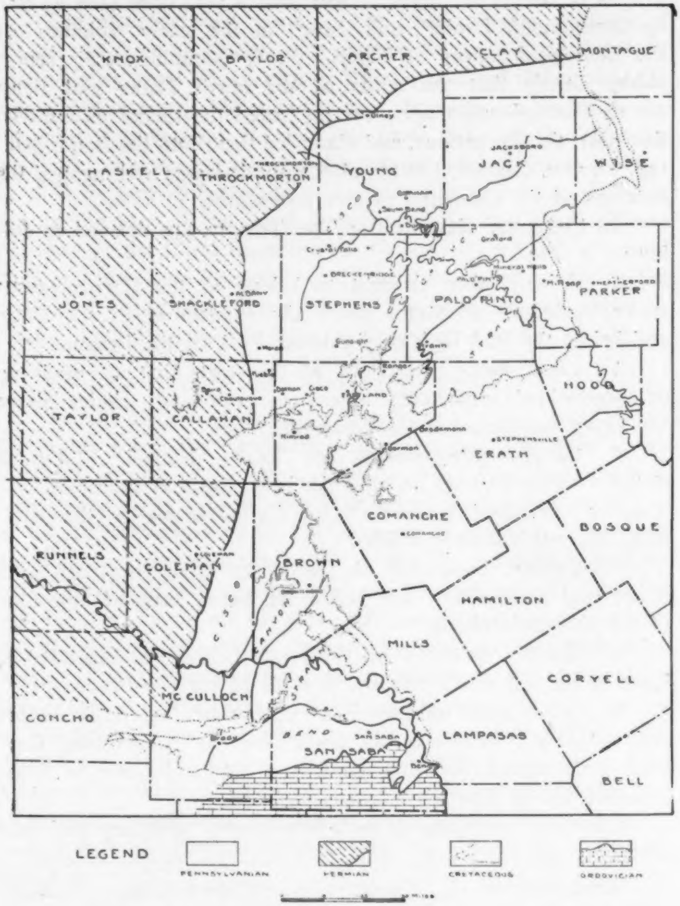
[1]Cummins, W. F., Southern border of the central coal field; Geological Survey of Texas Annual Report, p. 145, 188.

[2]Cummins, W. F., Geology of northwest Texas; Geological Survey of Texas Second Annual Report, p. 359, 1889.

[3]Drake, N. F., Report on the Colorado coal field; Geological Survey of Texas Fourth Annual Report, 1892.

[4]Tarr, Ralph S., A preliminary report on the coal fields of Colorado River; Geological Survey of Texas First Annual Report, p. 201, 1888.



PENNSYLVANIAN AREAS IN NORTH TEXAS

FIG. 1

Previous Geologic Work.

The only publications that deal essentially with the stratigraphy of the north Texas Pennsylvanian area have been written by Cummins[1],[2], Drake[3], and Tarr[4], in the early volumes of the Geological survey of Texas. Prof. Cummins in his report shows clearly that the strata of the north Texas coal fields are of Pennsylvanian age. He measured the section accurately, described the formations, and classified them into the Bend, Millsap, Strawn, Canyon, Cisco and Albany divisions and mapped the outcrops of the Cisco and Strawn coal seams.

In Cummins' classification the divisions are defined as follows:

6. Albany, then thought to belong to the Carboniferous series, included[5] all strata above the sandstones of the Cisco and below the Red Beds of the Clear Fork of the Permian.

5. Cisco, made to include[6] all the strata that are made up of interbedded sandstones, limestones and sandy shales above the heavy limestones of the Canyon division.

4. Canyon, unfortunately not clearly defined; Cummins states[6]: "This division includes the heavy beds of limestone and is easily recognized by the fact that the limestones of other divisions are much thinner bedded.

3. Strawn, embraced[6] all the strata in the northern area above coal seam No. 1 and below the heavy beds of limestone of the Canyon division.

2. Millsap, included[7] all the strata below coal seam No. 1 down to the top of the Smithwick shale of the Bend division

1. Bend, name proposed by Cummins[8] for black shales and limestone unconformably underlying the coal-bearing Carboniferous sandstones that contain a preponderance of Coal Measure fossils typically exposed at Bend.

Cummins' grouping of beds was purely arbitrary and was

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[5]Cummins, W. F., Geology of northwest Texas; Geological Survey of Texas Second Annual Report, p. 375, 1889.

[6]Idem. p. 374.

[7]Idem, p. 372.

[8]Dumble, E. T., Report of the State Geologist; Geological Survey of Texas First Annual Report, p. LXV, 1888.

based largely on the lithologic character of the sediments. Yet this has proved to be a very convenient classification, and with only slight changes it has been quite generally adopted.

The most detailed work on the Pennsylvanian geology of Texas was done by Drake[9] who mapped the area along Colorado River Valley from the vicinity of Brownwood and Coleman to the Llano Mountains. He adopted the classification proposed by Cummins but defined the divisions more definitely by choosing a certain limestone to mark the top of each division. Thus Drake's Strawn included the strata from the Smithwick shale below to the base of the Coral limestone above; the Canyon from the base of the Coral limestone to the top of the Campophyllum bed; and the Cisco from the top of the Campophyllum bed to the top of the Santa Anna Branch bed. The section as described by Drake along the Colorado River is shown on Fig. 2.

Extent and Method of Work.

The geologists of Roxana Petroleum Company in December, 1916, began the systematic mapping of the structure of the northern portion of the Pennsylvanian area. The need of a map similar to Drake's showing the principal strata was soon felt, and as the work progressed the necessary data was collected, and the map was slowly constructed. At the present time almost the entire Pennsylvanian area has been completely mapped. In doing this the outcrops of all the principal limestones have been traced by planetable and alidade method, and the sections have been measured and described wherever a change in the stratigraphy was observed. In constructing the general map only the outcrops of those limestones that could be traced continuously across the district have been shown. All possible correlations have been made by walking the outcrops. In all places where the outcrops were covered by patches of Trinity sand or lost beneath a wide belt of alluvium three criteria have been used in correlating the beds:

1. Comparing the sections.
2. Comparing lithologic characteristics.

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[9]Drake, N. F., Report on the Colorado coal field; Geological Sruvey of Texas Fourth Annual Report, 1892.

PENNSYLVANIAN FORMATIONS OF NORTH TEXAS

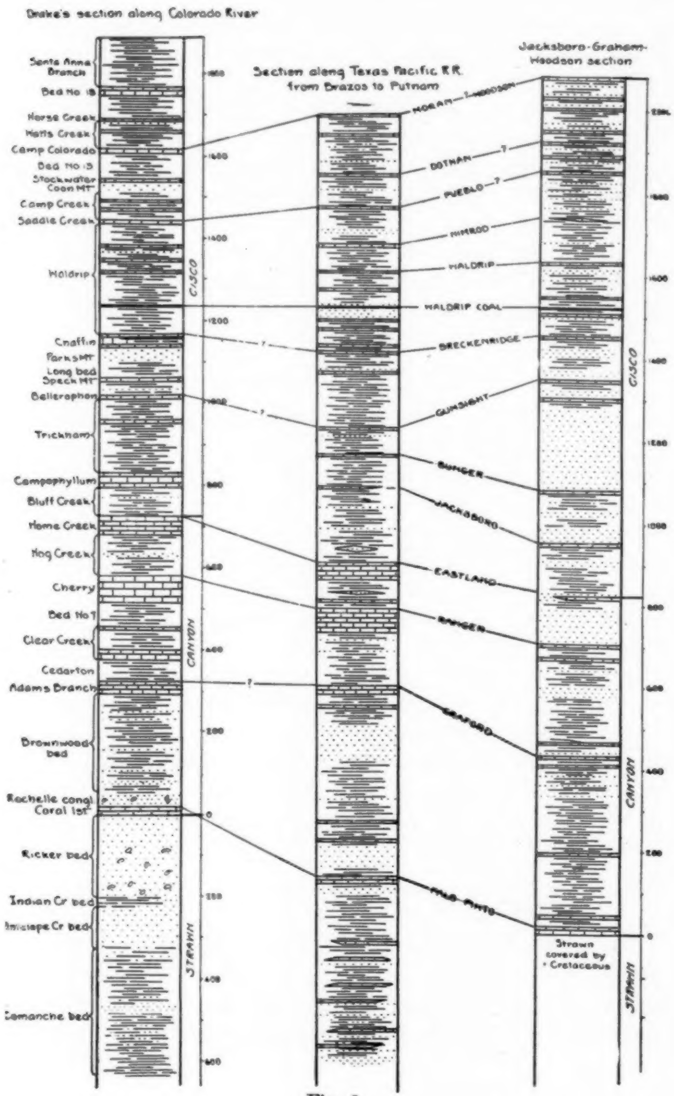

Fig. 2

3. Comparing the faunal groups, where the beds are sufficiently fossiliferous.

For example, the Waldrip limestone by its position in the section 20 feet above the upper coal seam is readily recognized; the Ranger limestone because of its greater thickness and chert content has definite lithologic characteristics; whereas the Gunsight limestone may everywhere be distinguished by its characteristic fauna.

It is planned to have the map published by the Geological Survey of Texas along with descriptions of the formations, sec--tion, and descriptions and plates of the characteristic and newly discovered fossils. Because of the present imcompleteness of the work and of the lack of time and space, only a summary of our work, stratigraphic section classifications and brief descriptions can be made here.

ACKNOWLEDGMENT.

The study and mapping of the outcrops has been the work of each geologist in the Texas division of Roxana Petroleum Company. The following men have contributed the most:

John Burtt mapped the northern portion.

Paul Applin, Jas. M. Armstrong and Sam Wells mapped most of the central portion.

Chester Hammill, Angus McLeod, Grady Kirby and Lloyd Wells mapped most of the southern portion.

Dr. R. C. Moore has named and classified many of the fossils collected and has contributed much to our knowledge of the paleontolgy.

Richard Conkling, head geologist, and Pres. Van der Gracht have contributed very largely by inspiration, advise and helpful criticism which has made the completion of the work possible. It is through their permission that the results are here set forth.

CLASSIFICATION OF FORMATIONS.

In classifying the strata of north Texas the divisions of Cummins and Drake have been accepted as far as possible. At the same time an attempt has been made to define the formations more definitely and to make the divisions as natural as possible. In doing this the method employed by Dr. Ohern[10] in classifying the formations of north-eastern Oklahoma has been followed.

The most persistant and easily recognized limestones have been chosen as division lines to separate the Canyon, Cisco, and Albany divisions and divide them into smaller units. Many of these persistent limestones from the tops of escarpments so that most subdivisions extend from the top of one escarpment to the top of the next escarpment above. This is shown in the small generalized section of the formations between Mineral Wells and Moran (Fig. 1). Thus the Cisco has been divided into seven subdivisions, the Canyon into four, and the Strawn into three as follows:

Upper Pennsylvanian—

- Cisco—
  - Moran
  - Pueblo
  - Waldrip
  - Breckenridge
  - Gunsight
  - Bunger
  - Jacksboro
- Canyon—
  - Eastland
  - Ranger
  - Graford
  - Palo Pinto
- Strawn—
  - Gordon
  - Mineral Wells sandstones
  - Brazos sandstone, etc.

Middle Pennsylvanian—

- Millsap—
  - Kiskapoo Falls limestone
  - Limestones, shales, and sandstones covered by Cretaceous.

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[10]Ohern, D. W., The stratigraphy of the older Pennsylvanian rocks of northeastern Oklahoma: State University of Oklahoma Research Bulletin No. 4, 1910.

Lower Pennsylvanian—
    Bend—
        Smithwick shale
        Marble Falls
        Lower Bend Shale

Brief Description of Divisions.

Bend

The strata of the Bend division outcrop only in a narrow belt around the Llano uplift, but they underlie the entire north Texas Pennsylvanian area. Three subdivisions have been made:

3. Smithwick shale
2. Marble Falls limestone
1. Lower Bend shale

The Lower Bend shale is exposed in but a few places along the unconformable contact with the Ellenberger limestone. It varies from 10 to 50 feet in thickness, is quite petroliferous, and most commonly is yellow-grey, soft, and clayey, but in places it is fissile more like the Smithwick. Locally it is entirely absent near the outcrop, but is recorded in nearly all well logs north of the outcrop. The most characteristic fossils are *Chonetes unbonatus* and *Leda bellistriata* which are found even in deep-well cuttings from the oil fields.

The Marble Falls limestone is in conformable relationship with the overlying Smithwick. For the most part it is grey and grey blue, in places nearly white, in others black. Especially in its lower part it contains considerable black chert. Locally the limestone is interbedded with light-grey and yellow-grey shale, and well logs north of the outcrop show sand in places. The most characteristic fossils are *Productus morrowensis and Productus cora.*

The Smithwick shale varies in thickness from 200 to 400 feet and is typically a dense, black, finely laminated, brittle, fissile shale containing concretions and ferruginous seams. In places the black shale grades into a sandy, blue, and yellow-grey layer above, and below it is interbedded with thin, hard, very dark colored limestone.

The unconformity above the Bend series and the over-lying

beds is very marked. Around the Llano uplift the Smithwick shale is unconformably overlain by Strawn sands; in places the upper sands lie directly on the Marble Falls limestone.

Millsap Division

Although in 1912 the Geological Survey of Texas dropped the name Millsap for the lower series of limestones and shales beneath the typical Strawn sands and conglomerates, it now seems best to restore this name, as the three lower limestones are found to contain a fauna quite different from the overlying Strawn beds. This division is here defined as those beds between the Smithwick shales and the top of the limestone members outcropping in Parker County. The best exposure of the Millsap may be seen at Kickapoo Falls, 10 miles south of Weatherford. Here the strata are made up of thick, massive, dark-blue shales. The limestones are lenticular, unevenly bedded, and can not be traced continuously in drill records.

The basal portion of the Millsap contains commonly a light-colored quartz sand. In places this sand lies directly on the black Smithwick shales and in others is separated from the Smithwick by blue marls and thin limey layers. When miscroscopically examined this sand is found to contain grains of black slate and black chert that resemble very closely grains from the Bend strata. It is thought that this sandy phase of the Millsap represents the line of unconformity between the Bend and the younger Pennsylvanian above. The exact age of the Millsap fossils has not been definitely determined by Dr. Moore, but it is his opinion that they are of middle Pennsylvanian age, at least they are much younger than the Bend fauna.

Strawn Division

The Strawn strata outcrop in a broad, irregularly shaped belt along the eastern border of the Pennsylvanian area.

The most complete section can be traced in the valley of the Colorado River and in the valley of the Brazos between Mineral Wells and Millsap. The division consists of shale, thick sandstones, conglomerates, and a few lenticular limestones. The shales are quite fossiliferous, and good collections have been made from several horizons. The sandstones in many places contain fragments of coal plants, which show evidences of rapid,

near-shore deposition, for although they may be traced for considerable distances they do not persist at a given horizon but change in short distances to beds of shale or conglomerate. This horizontal variation makes it impossible to correlate with any exactness the beds of the Brazos River Valley with those of the Colorado River section. The Brazos River section is thicker, and the individual beds of conglomerate and sandstone are more massive, coarser grained, and more numerous than in the Colorado River section. In both sections the basal beds of the Strawn and Millsap divisions pinch out northwestward so that the younger beds progressively overlap the older strata, and wells toward the west reach the Smithwick at progressively shorter distances through the Strawn and Millsap. The Millsap is entirely gone in wells drilled south of Gorman and west of Breckenridge and Moran (see Fig. 3).

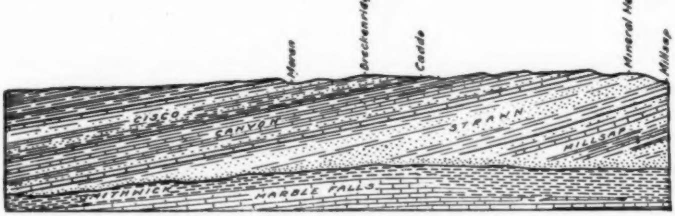

Diagram showing the stratigraphic relationships of the Pennsylvanian beds. (*Fig.* 3.)

The coal seam that outcrops at Strawn, Rock Creek, east of Mineral Wells, and at Bridgeport pinches out in a short distance to the west, and the test holes 15 miles west found black shales with showings of oil where the coal should have been found in the section.

Canyon Division

The Canyon division outcrops in a belt about 30 miles wide across the central part of the Pennsylvanian area. Four

subdivisions approximately equivalent to the formations in Drake's Colorado River section have been made as follows:

New Brazos River Section

4. Eastland
3. Ranger
2. Graford
1. Palo Pinto

Colorado River Section

4. Home Creek Bed
3. Cherry limestone bed
   2c Bed No. 7
   2b Clear Creek bed
   2a Cedarton bed
2. Adams Branch limestone
   1b Brownwood bed
   1a Rochelle conglomerate
1. Coral limestone

The Palo Pinto formation is everywhere easily recognized in well logs and in the field because it forms the lower-most series of thick limestones in the section above the Strawn sands. The lower member is a massive limestone that forms a prominent scarp dividing the Strawn area from the Canyon.

The Graford formation is composed largely of shale members with some thin limestone and a little sand. The upper member, the Graford limestone, is one of the most persistent and may be recognized by the greater height of its scarp than the other limestone members of the formation. These limestones are quite fossiliferous, but the shells on the whole are poorly reserved.

The Ranger formation is approximately 215 feet thick and includes the strata from the top of the Graford limestone to the top of the heavy Ranger limestone above. The Ranger limestone forms a scarp that may be seen west of Ranger and is responsible for the beautiful and wild topography in western Palo Pinto County where Brazos River has cut deep canyons into the scarp. The abundance of chert nodules and brown iron stained layers in the Ranger limestone distinguishes it from all other members of the Canyon division.

The Eastland formation varies from 100 to 175 feet in thickness and includes all the strata from the top of the Ranger limestone to the top of the Eastland limestone, called more commonly by Texas geologists the Caddo limestone. As the name Caddo has already been pre-occupied by a limestone in Kansas the name Eastland has been chosen for this Texas limestone. This upper member is well exposed in a creek bed half a mile east of Caddo and in the Caddo oil field. Northeast of Finis

in northern Palo Pinto County it can not be traced with certainty, and in southern Jack County where the Eastland limestone is expected in the section a calcareous sandstone and conglomerate appear, so that the top of the Canyon in this area is less clearly defined. The Eastland limestone is distinguished from the other limestones of the Canyon by its stratigraphic position above the thick and massive sandstone beds and below the fossiliferous shales and ferruginous sandstones of the Cisco.

Cisco Division

The beds of the Cisco division outcrop in a belt about 18 miles wide in the western portion of the Pennsylvanian outliers. As mapped and described in this paper this division includes all strata from the top of the Eastland limestone and its Equivalents As to the top of the Moran limestones in the Moran oil field. The division as made here is similar to that of Cummins with the stratigraphic boundaries more definite.

The following subdivisions for the Brazos River section have been made and compared with Drake's Colorado River section:

New Brazos River Section	*Drake's Colorado River Sec.*
7. Moran	7. Camp Colorado bed
6a Dothan	6a Stockweather bed
6. Pueblo	6. Saddle Creek bed
5. Waldrip	5. Waldrip
4. Breckenridge	4. Chaffin beds
3. Gunsight	3. Speck Mountain limestone
2. Bunger	2. Trickham bed
1. Jacksboro	1. Campophyllum bed

The Jacksboro formation, composed of approximately 60 feet, limestones, sandstones, and a little shale, contains the fossiliferous Campophyllum bed that is everywhere recognized. It is present only in Jack and the eastern part of Young counties. The upper member of the formation is the Jacksboro limestone, which plays out in the sandstone hills southwest of Jacksboro and appears again in the section north of Finis on the Mineral Wells-Graham road.

The Bunger formation includes about 230 feet of thick, poorly bedded, lenticular, dark brown sandstones and sandy shales with a few thin limes. The upper member is the Bunger

limestone, which is 2 to 4 feet thick and the lowest persistent limestone in the Cisco division. In places it is dark, yellowish-brown, dense, and heavy; in other places it is light grey and coarsely crystalline. In the section west of Finis a dark carbonaceous shale occurs near the bottom of the Bunger, but it is only a local phase.

The Gunsight formation includes approximately 100 feet of shales, sandy shales, and thin limestones. The upper member is the Gunsight limestone that forms a continuous ledge where not obscured by overlying sands and conglomerates. It is easily recognized where the shale above and below are well exposed, because in most places these members contain a characteristic and prolific group of fossils. A spiney coral, *Lophophyllum profundum var radicosum,* and a large number of small forms of *Productus longispinus* are characteristic. It was from the shale bed above the Gunsight limestone that the ammonites described by Hyatt and Smith were collected.

The Breckenridge formation consists of three persistent and lithologically similar limestone members, upper, middle, and lower respectively, separated by thick shale beds and lenticular sands. In places a fourth limestone member is present about 10 feet below the lower. These three limestones form escarpments around the east end of the Breckenridge oil field.

The Waldrip formation is characterized by a coal bed below the Waldrip limestone which forms a conspicuous scarp throughout its outcrop. At Cisco the limestone is a dense, crystalline, and dark grey fossiliferous bed, but in the northeast part of Shackleford County west of Breckenridge it changes to a sandstone and disappears. Another limestone, however, occurs in the section about 40 feet lower and can be traced farther north. Northeast of Newcastle the formation is composed largely of sand. In places where the coal does not outcrop the Waldrip limestone can be identified by the large numbers of large crinoids on its surface and from the characteristic fossils from the shale just below. *Enteletes hemiplicata* and a rather large *Chonetes granulifera* are diagnostic of this stratum.

The Pueblo formation is bounded by the Pueblo limestone, which is yellow, fossiliferous, and impure. Near the Red Bed

line in Stephens County it changes to sand and loses its identity, but just below its horizon is a thin limestone abundant in *Myalina* fossils, which characterize this bed. The series of members in this formation is so variable that no one section is typical.

The Moran formation is marked in its upper part by three thin limestones. The bright yellow color and the presence of many small light-colored gastropods in the middle stratum make this formation one of the easiest to recognize in the whole Pennsylvanian section. Below the Moran limestone, the uppermost yellow bed, are the usual light-colored shales and reddish sands common to the upper part of the Pennsylvanian. About 160 feet below the top is a prominent single limestone that outcrops near Dothan and is called the Dothan limestone. Northward it pinches out into sands and shales. Below the Dothan limestone are 60 feet of shales and sands down to the Pueblo limestone.

Summary

A new classification for the Pennsylvanian strata of Texas has been proposed in this paper. The old divisions of Cummins have been followed as far as possible, but the stratigraphic boundaries have here been more definitely established by the completion of a new geological map and a careful study of the fossils. The divisions have been subdivided into formations by using the more easily recognizable and continuous limestone to mark the top of each subdivision.

The top of the Smithwick shale has been chosen to mark the division between the Bend series and the Millsap division. The top of the limestone members outcropping in Parker County marks the upper horizon of the Millsap division; the series of sandstones and conglomerates between the Millsap limes and the Palo Pinto limestone makes up the Strawn bed. The Canyon division includes all formations from the bottom of the Palo Pinto limestone to the top of the Caddo limestone; and the Moran limestone is tentatively chosen for the top of the Cisco division separating the Pennsylvanian beds from the Permian, for it is believed that above this line Permian fossils begin to appear in the section.

DISCUSSION

Mr. Schuchert: Mr. Chairman, I want to congratulate Dr. Plummer and his staff upon this excellent work that he has done, not only in mapping these limestones from place to place but also in observing the characteristics of the sediments, watching for the muds and the sands and looking for the origin of those sands and their significance in paleogeography. I am particularly delighted to see the way he takes hold of the fossils. Any man who has studied Pennsylvanian fossils knows how difficult they are to work out in the minor horizons, it is one of the most difficult of tasks we have in the paleontology of Paleozoic stratigraphy and he has hit the nail on the head.

It is not that we are looking for single fossils; we now look for combinations of species. When you find 1, 3, 10 and 4 together you can depend on it that you have a definite horizon, and when you have another combination you have probably a different horizon. This is what he has done, and in this way we are going to progress and get a determined stratigraphy.

Mr. Cummins: Mention has been made of my having gone across this section in the early days. I went from the east towards the westward in making the section. Going down off the Cretaceous from the eastward, the first of the Pennsylvanian that I came to was situated at Millsap, and then going on, putting the other names in. These divisions were arbitrary at the time. Later along the coal bed No. 2, which is the workable bed at Gordon, I took as the horizon for determining the beds of the Strawn, and finding this coal bed at Millsap I abandoned the name Millsap and combined all the strata belonging to that part of the field with the Strawn. Later along some of the more recent examiners had suggested to me that I was wrong in abandoning the Millsap because there were found many, or some things in there that were not exactly characteristic of the other part of the Strawn. Well, of course there are no objections to calling it, that part of it, the phases of the Strawn Division, but I still think that it belongs to what ought to be simply the Strawn Division, because I did not intend originally, as Mr. Plummer and his co-laborers have done, to divide up these divisions into the separate beds, and therefore they might call that—or

the beds they have below what they think ought to be the Strawn, in the vicinity of Millsap—they might call that the Millsap Beds. It is not the same thing.

I abandoned the name Albany, because the Albany and Wichita occupy identically, stratigraphically, the same position, and there is no use in having two names for the same thing, and if I have to refer to the southern field now I say the Albany phases of that division, and I believe I gave you yesterday why I got confused and made a mistake. It is as easy to perpetuate a mistake as it is to perpetuate the truth. Now there are a great many elements of error that come in a man's work. One of them is pure and unadulterated ignorance of the question we are discussing. Another is lack of information—and several others. If I had known as much about the Albany as I did afterwards, I wouldn't have made the mistake of calling it Albany instead of Wichita at the beginning, and would not have been the cause of these later geologists perpetuating that mistake that I made. Probably they didn't know that I had abandoned the name of Albany, which of course I suppose Mr. Hill will say I had the right to do, because he is the Prince, I believe—the Prince of Abandonment.

Mr.David White: This is a tremendously interesting paper and I cordially endorse Dr. Schuchert's expressions of appreciation of the work that has just been presented. At the same time the relation of this paper to that presented yesterday by Dr. Udden should be noted for we are apt to lose sight of the important principles that Dr. Udden has brought out in his discussion of the progressive uplifting of the Balcones Escarpment. Such a conclusion is most logical; the movement is to be expected and conforms to a general rule. It is quite to be expected that some later Paleozoic formation may have lapped upon the Escarpment area only to be eroded from the uplifted areas of the latter. In fact the more elevated areas of the uplift may have been stripped to the crystalline prior to the Cretaceous deposition.

This phase of the discussion harks back to the discussion of yesterday regarding the occurrence of post-Ellenburger and pre-Bend beds in the Carboniferous basin of North Texas.

There is reason to believe that formations older than the bend and younger than the Ordovician lie in the Paleozoic basin

of North Texas. If exposures other than those in the Criner Hills only were available for inspection, one might conclude that the Silurian and Devonian were absent from Red River Valley. However, the exposures in the Arbuckle Mountains, which show formations representing these periods dipping southward beneath the Pennsylvanian and Red Beds series, are indisputable evidence that these formations pass for unknown distances to the south and therefore that they almost certainly extend into the Paleozoic basin of North Texas. Their distribution in that area depends, of course, on the configuration of the basin in Silurian and Devonian time. Their absence from the uplifts of the pre-Bend age is probably due, in some cases at least, to erosion just prior to the Bend.

Another point in regard to the stratigraphy: The suggestion of lateral continuity between the Cherokee and the Millsap-Bend I regard as impossible. The idea is perhaps the outgrowth of the tendency on the part of many geologists to apply the term Cherokee in a broad sense to the Potsville rocks exposed along the eastern edge of the Oklahoma-Arkansas coal region. The inclusion of the Middle and Lower Potsville of these States in the Cherokee is erroneous. The typical Cherokee, as developed in southeastern Kansas, includes only the uppermost Potsville and its lowest beds do not long antedate the base of the Hartshorne sandstone of Oklahoma. The older formations of Pennsylvanian age in this region were earlier deposited in the old Potsville sea and only the later horizons are possibly represented in the relatively narrow buried estuary, which in Upper Pottsville time stertched northeastward toward southwestern Iowa.

One point more: It may be worth while to mention that some years ago I made a collection of fossil plants from the coal mines in the vicinity of Newcastle. The fossils have never been fully determined or described, but the review of the material in the field is the basis for a tentative reference of the beds to a stage in the Monongahela of the Appalachian trough. The plant-bearing shales for the Newcastle mine were found to be remarkable for the great number of spiral coprolites which they contained. I never saw coprolites of this character so numerous at any other locality. I would like to know if Mr. Plummer's conclusion is in agreement with mine that the horizon of the coal at

Newcastle is somewhere near the top of the Pennsylvanian, that it to say whether the evidence of the vertebrates and plants is in accord.

Mr. Pratt: I am very strongly impressed with Mr. Plummer's paper. I happen to know that it has been hard to get real contributions from men who are working with companies and it has been a great deal of trouble to get papers of that kind presented to this meeting. I think most of us in North Texas believe the Roxana Petroleum Company is doing the most thorough, the most extensive geological work of any of us, and I think it is a fine example for the rest of us that the Roxana Petroleum Company comes out here, through its men in charge of its work in North Texas, and gives a real contribution on the stratography of North Texas.

Mr. David White: As one entirely unbiased, I would like to confirm that opinion. I would also like to emphasize the necessity for the hypothesis, already brought out by Mr. Plummer, that toward the northeast, somewhere in the region of the Red River valley, a Mississippian-Pennsylvanian land barrier existed which is now bridged by later Pennsylvanian, Red Beds, or Cretaceous strata. The existence of such a land mass is predicated by the sediments (clastics) of the Jack Fork, Stanly, Caney, and Atoka formations as well as by the fossils. The sediments of these formations could hardly have been derived from the Ozark uplift, nor does it seem probable that they could have originated in the areas now marked by the Arbuckle-Wichita uplift.

Chairman: Where do you think that land mass was, Dr. White?

Mr. David White: Like Dr. Beede, says, we will let the driller find out.

Mr. Fuller: I should like to point out the possible significance of the carbon ratios in coals with relation to the possibility of an old land mass, or rather an area of disturbance, beneath the Cretaceous to the east. Taking up the carbon ratios—that is, the ratio of carbon to volatile matter in pure coal—we find that in Montague County, at Bridgeport in Wise County, at Millsap in Parker County, and at Thurber in Erath County, the ratio, according to the analyses of the United States Geological Survey, is

about 64, which is exceedingly high. From the localities mentioned, the ratio grades off rather rapidly to the west to 50 or less at Newcastle in Young County, Cisco in Eastland County, etc. It is fairly high in Brown county, near the north edge of the Central Texas Uplift, but decreases northward.

The high carbon ratio along the east edge of the Carboniferous basin apparently indicates a disturbance beneath the Cretaceous as great or greater than around the Arbuckle, the Wichita or the Central Texas uplifts. Whether or not there is actually an ancient buried land mass, I cannot say as yet, although I believe there is.

WATER PROBLEMS OF THE BEND SERIES
GENERAL DISCUSSION

By M. L. Fuller *and Others*

I was asked simply to open the discussion on the question of water in the bent. It is a question which is of vital importance to the future development of this field as well as of general scientific importance in the development of oil fields in general. All agree that the location of the pools and fields depend to a large degree upon water. To a minor extent the location of wells, drilling methods, behavior of wells, the productivity of sands, the handling of casing, and many other problems are determined by the presence or absence of water.

In the North Texas field, two radically different views are held. An official of the T. & P. Company has stated that none of their wells have shown water in the Black Lime, while some geologists who are familiar with the field have represented that many wells show water in the Black Lime.

Perhaps both may be right, or at least right in part. It is probable that most of the T. & P. wells do not show water. On the other hand, those of you who are looking for water will quite likely find references to it in the logs of many wells. The object of this discussion is to bring out such facts as you may have. I started to collect water data in the field, but was not able to accomplish much. At the very start marked differences in the opinions of the various drillers working on the same well were found, and the result was somewhat like that in Dr. White's story yesterday—some had a whole lot of water and some had mighty little in the same well.

My men went directly to the drillers to get as near the original source of information as possible, and made inquiry as to how much of the water actually came from the sands or other material of the Bend series and how much might possibly have leaked in from above. We found it very difficult to get a correct answer. In our own Allen well, for example, we had water with

the oil at 3070 feet, but we cannot ourselves say whether that water came in at the bottom or from around the casing. Perhaps it might have been determined if the drill had not become jammed at the bottom, preventing further work.

In many cases the reports on the logs do not agree with what the drillers tell one personally, even when one is on friendly terms with the latter and they are presumably telling the truth.

I think, perhaps, many of us have been altogether too busy in hunting structures in the past. In other words, we have been rock hounds instead of geologists. In the future we must give more attention to the water problem. All are familiar with the fact, I think, that water decreases with depth in most oil fields. This field is not an exception. The extent to which the field will be dry, the localities where it will be wet, and the bearing the distribution of water will have on search for oil are among the questions open for discussion.

Of course, in West Virginia, where the deep sands are dry, we look for oil in the synclines, but in Texas it is known that the anticlinal principal prevails and that as a general rule the oil will be found along the crest of the Bend Arch—assuming for the moment that the Arch is there.

On the Arch there are various domes and basins. Now is there any water in the basins on top of the Bend Arch? If so, what effect is that going to have on the location of wells over those depressions? So far, I think it is true that wells over the depressions have not secured as much oil as the wells on the bulges on the main Arch. Possibly that may not prove true for the whole field. At any rate, it is a point which is well worth discussing.

Assuming that the anticlinal principle holds true as a whole for this field, it becomes desirable to know the lateral limits of the dry or nearly dry zones, the extent of the wet but not saturated zones, and the boundaries of the saturated zones. Again, we should know to what extent water will prevent the occurrence of oil on the minor structures in synclines.

Another question to be answered is at what point does fresh water penetrating down the dip become a source of danger? This is an important problem in all the field, but especially pertinent

in determining the probabilities of extending the main field into Coleman and Brown counties. Again, the question of faulting is one of great importance. Faulting is very pronounced in the south field, especially near the Colorado river, and to the south, and probably has a most important bearing on the water problem. How far north will this pronounced faulting extend? I think most of us will admit that little production is likely south of the Colorado river, but how far north of the river the dry territory will extend is an important question, which will depend for its answer largely upon water conditions which, in turn, are dependent to a considerable degree upon the action of faults in permitting the penetration of water and the migration of oil. Still again, what is going to be the effect of water on the permanency of production? What steps must be taken for the protection of wells?

These are a few of the problems which were in mind when this discussion was planned. We wish to hear from anyone with facts bearing on the problems. Every substantiated fact in regard to water in the Bend is sure to be of value. It should be thoroughly established, however. A drillers statement, unless there is other evidence, is an uncertain basis for conclusions.

I have not planned a paper on this subject myself, but I may state in a brief way my own tentative views as to the distribution of water. I feel that water is likely to be present in the Bend in considerable amounts east of the east line of Stephens and Eastland Counties, north of central Young County, and west of the west line of Eastland and Stephens Counties. The exact limits of the water are far from definite. We are dealing with two things; one of which is the residual salt water in the rocks, and the other the fresh water penetrating downward from the surface. Personally, I do not look with very much favor on territory south of the central part of Comanche and the northern part of Brown Counties.

These are broad generalizations based on relatively little data of a definite nature. Many of you men are familiar with individual wells and probably have exact data. I should like to hear from those of you who have such facts in mind.

Mr. Suman: I have known of several wells in North Texas which produce water in the Bend formation. There is one at

Lovers' Retreat, west of Mineral Wells about thirteen miles, which has water in the Bend. There is a well or several wells, which produce water from the contact, or what is assumed to be the contact of the Bend formation and the Ellenberger limestone, particularly the well of the Humble Oil Company at Sipe Springs. The Texas Company well in Young County, on the Graham Ranch, I think is making a small amount of water from the Bend formation. I know of a Texas & Pacific Coal Company well at Strawn which would make at the time drilled a very considerable amount of salt water from the Bend formation, about 3,200 feet in depth. There are other instances. I know of cases in which the water from the Strawn has penetrated casing seats and has given the impression that water was coming from the Bent when it wasn't. I speak particularly of a well drilled by the Mid-Kansas Company at Caddo, in which the water from the Strawn, while the well was shut down, broke through both the eight-inch and six-inch casings, and while this well was 3,600 feet deep there was no question but that the water came from the Strawn formation at about 2,100 feet. There seem to be in that case quite a few people who would assume that the water was coming from the Bend, after the well had been drilled, but it is very positively known that the water came from the Strawn. The casing was pulled and a new seat was found for the pipe and the water was cut off.

In addition to those mentioned the following list of wells are making water from the Bend formation.

Lone Star Gas Co. No. 1 Della Cassell-Breckenridge District
S. D. Felt No. 1 Moon, Breckenridge District------3444 ft.
T. & P. Coal Co. No. 1 Rogers, Caddo District------3265 ft.
T. & P. Coal Co. No. 1 Bradford, LaCasa District--3601 ft.
Gulf Prod. Co. No.1 Brelsford, Eastland County----3400 ft.
Crescent Oil Co. No. 1 Gray, Comanche County----2985 ft.
Walker & Caldwell No. 1 W. R. Jones, Comanche Co. 3260 ft.
Gulf Production Co., No. 1 K. Stoker, Breckenridge Field
Mid-Kansas Oil & Gas Co., No. 1 R. O. Jackson Caddo Field
Prairie Oil & Gas Co. No. 1 Powers, Caddo Field
Prairie Oil & Gas Co. No 1 Corbett, Stephens County 3250 ft.

Mr. Johnson: It is extremely probable from the work of

Mr. Rogers in California and Mr. Neil of Butler County, Kansas that the water from the Bend has a characteristic analysis. It will doubtless show some geological difference or variation but the analysis ought to be a great deal of help in determining whether or not any particular water is from the Bend.

Mr. White: I would like to correct the impression that there was water in the well in Young County from the Bend; to the best of our knowledge there is not. Any water they are getting from that well is from a depth of 3,100 or 3,200 feet. They report two-thirds of a barrel an hour from 3,200 feet and dry on below that, and their 5 3-16 inch casing is set at about 2,750 feet. They were not able to put that casing down far enough to shut off the water. So far as any of us know, there was no water in the Bend in the Graham well. And furthermore, so far as I know, the Goode well of the Roxana Company has no water in the Bend formation, which is only some ten miles away from the Graham well, but I believe Mr. Plummer can corroborate this.

It struck me that there was a little conflict in Dr. Fuller's remarks as to the water, in depth. He told us that in the deeper wells in West Virginia and Pennsylvania the water gets less as they go down and the deeper sands are dry, but down here in Texas, he tells us he expects, as we get deeper in the Bend, to get water to the west of Jack and to the north of Young and Palo Pinto Counties.

Charman: I didn't think he said that.

Mr. J. C. White: He has also in private conversation told me that he was afraid of Young County being on the edge of the water, the idea being that the water was going to be heavier as we go down, whereas in the East it gets less as they go down.

Mr. Fuller: I wish to say in explanation, to put myself clear, that I mean that water decreases in going down at any one point. That is, if one drills at Ranger, for instance, he has water in all of the Strawn formations, and possibly at the top of the Black Lime. Below the latter horizon, little if any water has been found, but that does not mean that one will not get water at the same or greater depth at another locality. At any individual point the tendency is for the water to decrease with the depth.

Mr. J. C. White: With reference to finding water in the oil

sands, I would say in West Virginia we have very little water in the oil sandstone series. In such cases (absence of water) the oil, of course, is found in the syncline as well as on the slopes. But over in Pennsylvania, near the Washington County line, in that very deep well drilled by the Peoples Natural Gas Company to a depth of 7248 feet they had a little oil and enormous quantities of salt water at a depth of 6250 feet in the Oriskany Sandstones of the Devonian. Also below that about 300 feet they had enormous quantities of water in the Niagara limestone. The question seemingly is one of porosity and of a porous connection with the sources of water. The Oriskany Sandstone and Niagara Limestone of the Geary well come to the surface in Lake Erie, nearly 100 miles distant and doubtless the water in these deep lying beds get across to them there. If it were a question of losing water at great depths, we wouldn't have had any at 6250 feet in that well. I would say in those other deep wells of West Virginia they have found no porous beds below the Big Injun Sand. In the Goff well they cased off all water at about 1600 feet. In this well they drilled to a depth of 7,386 feet and they found no water up to that depth. About 5000 feet of that, of course was close shale, and couldn't hold water, but at the bottom they had some limestone—that may not have been porous—but there was no water whatever, so far as the drillers could determine, in that entire depth of 7386 feet below this 1600, and the reason, I think, is those rocks were not originally porous, and if they were they have had no access to water because they most probably became non-porous before they reached these surface waters.

Mr. Shaw: Mr. Fuller and I find ourselves in utter disagreement on the matter of dry sands. He believes in them and I don't. Some ten or twelve years ago Munn and I gave a good deal of thought to the question of decrease of water with depth in the Appalachian Fields. We discussed the phenomenon with others and it came to be spoken of as "Munn's Mystery". However, that 10 or 12 years is not as long a period as Mr. Fuller has been working on ground water.

It seems to me that we very commonly make a mistake in failing to distinguish the difference in meaning between the expression "water bearing" and "water yielding." We do not dis-

tinguish between the bed which is dry and the bed which has water but will not yield it up. There are a number of perfectly well known conditions under which a water saturated bed will not yield up its water at all, as I pointed out in a discussion of Roswell Johnson's paper on "the role and fate of connate water" and elsewhere. The conditions were later illustrated by Rogers in his San Joaquin Valley paper. It is a rather important question because of its connection with the occurrence of oil in synclines and the efforts to explain such pools by inferring that a stratum of sand may be empty in anticlines but may have oil under strong head in synclines.

Mr. Fuller: I think that's getting on a theoretical question far aside from the north field. It is very interesting, and I have read Mr. Shaw's paper, I might say, with much interest. I want to know how, if the water isn't there or is there, how to get the accumulation of oil in the West Virginia fields at the bottom of the syncline to a working hypotheesis. I think Mr. White will agree that that's the place to work from. I would like to have Mr. White's statement of that, and also Mr. Shaw's on his explanation.

Chairman: Dr. Shaw, can you answer his question?

Mr. Shaw: It seems to me that there are several conditions which might lead to the occurrence of oil in synclines, and the fact that oil *does* occur in synclines is poor evidence of dry or partially dry sands. I think most of us will agree that lithology—the arrangement of small pored and large pored lenses of rock—may absolutely block the most strenuous efforts of a perfectly developed anticline to pull oil out of a hole alongside. The subject is discussed in some detail in the paper on "the absence of water in certain sandstones" to which Mr. Fuller refers and in less detail elsewhere.

Mr. Hager: Mr. President, there certainly is positive evidence that there is water in the lower Bend Series. The Never Mind well which was drilled by the Producers south of Trickham is producing today a very strong stream of sulphur water between the Ellenberger and the base of the Marble Falls Limestone. In the Hart well six miles west of Brownwood, the drill struck a good flow of water at about 2200 feet, just before it penetrated the Ellenberger. The Lowe well southeast of Brownwood is

flowing somewhere near ten thousand barrels of water a day from the bed encountered just before the Ellenberger was reached. Now as I understand it, the Magnolia's deep test well at Coleman has also struck considerable water. I haven't seen the water but understand that is the condition. Those other three wells I know yield copious supplies of water.

Mr. Wrather: It has been my observation that the Bend formation is unusually free from water in the Eastland and Comanche County district. In the Strawn formation which immediately overlies the Bend, salt water is usually present in the sands. In many places there is water in the limestone of the Canyon series which lies above the Strawn beds. But through the oil producing districts of the above two counties there seems to be little or no water present in the Bend.

At the contact between the Bend and the Ellenberger limestone there is an unusually persistent sulphur water horizon. This horizon is traceable practically all the way from the region of outcrop of the Bend and Ellenberger around the Llano Uplift, northward into Stephens County, or in other words, as far northward as the Ellenberger formation has been reached by deep drilling. The water found at this horizon is nearly always sulphurous and is sometimes characterized by a peculiar sweetish taste, but personally I know of no place where strongly saline water has been found. Occasionally, as around the Duke well in Northern Comanche County, no water whatever is found on the contact, but in Western Comanche County near Sipe Springs the characteristic sulphur water has been found at the expected horizon.

It seems true that in a general way the region over which the Bend formation produces oil and gas may be divided into two districts; a southern or sand area, where the major portion of the production comes from true quartz sand, and a northern or lime area, where the production is derived from porous lime containing little or no grit. The oil in Comanche County comes from coarse sand; so does most of the oil from below 3200 feet in the Ranger pool; but the oil from the 3200 foot sand found in the Ranger pool is often called a "lime sand" pay, and seems to be composed largely of porous lime with a small amount of sand.

In Stephens County the oil in the Parks and Caddo pools is derived from porous lime.

It may be a mere coincidence but most of the reported water found in the Bend formation is in Stephens County; the water being found at horizons from 200 to 400 feet below the usual oil producing horizon it will be noted that these reported water showings in the Bend formation are in the region where the oil is derived from porous lime. I have not personally investigated any of these water showings in this district, but the reports have come to me from sources which I consider entirely reliable, and I have no doubt that water has been found at the reported depths which seem to be undoubtedly in the Bend formation, though usually below the pay horizon. Water is beginning to give trouble in the Ranger townsite in wells which produce from the 3200 foot sand, but it seems probable that this may be leakage water from sands found in the Strawn beds higher up. In the early stages of development wells in this part of the field were rather carelessly drilled and cased, and it is likely that the water which is now appearing is derived from sources outside the Bend series.

As far as development has progressed to the present time, the statement seems to be true that the Bend formation in Eastland and Comanche Counties is relatively very free from water, while water is present in Stephens County to a limited extent, though even there it does not seem to be present in any unusual quantity. This fact raises rather an interesting speculation as to just what extent water pressure has been influential in accumulating oil in the sands where it is now found.

Incidentally I might mention that the physical characteristics of the oil seem to be the same whether it is found in porous lime or in sand.

I don't know. My idea is, the Bend is, relatively speaking, a very dry formation. It is generally conceded that the Strawn formation lying immediately above the Bend, is very copious with water almost generally, particularly in Stephens County, where they have to use extra strong casing, five-eighths casing, in order to protect against this water. The Bend is relatively dry, but at the base of the Bend is uniform water, which in a few cases produces some oil also.

Whether these general statements will be borne out by more facts, I am very interested in finding out, and it is a question of contributions of specific instances from men who are familiar with individual wells and when they know that their conclusions are correct, and that's the thing I am very anxious to have brought out at this meeting.

Mr. Pratt: I have in mind the logs of two T. & P. wells, which I think will bear investigation, and both wells had salt water which surely came from the Bend, not from the Ellenberger. I refer to the Long No.1 in the northern part of Erath County where they found oil at about 3400 feet, with salt water in black beds, 100 feet below the oil, and another, Rogers No. 1 immediately north of the town of Caddo, Stephens County, where they went into salt water in black beds at 3253 feet.

As to analysis of water from the Bend—I mean water from the Ellenberger—we have sampled and analyzed water which comes from the equivalent of the Ellenberger, according to Dr. Udden—I think I am right—in a well drilled in Cotton County, in the southern part of Oklahoma. We find this water to have certain characteristics in common with the sulphur water from the Ellenberger in Comanche County, Texas, 150 miles to the south.

Mr. Matteson: In the Grosvenor well in Brown County there was a tremendously big syncline which had 1300 feet of Bend formation and was drilled through to the Ellenberger, and they encountered very little water until they struck the contact of the lower Bend and the Ellenberger. The Bailey well four miles to the east of there has been drilled 700 feet into the Marble Falls Limestone and has encountered very little water. They had about a barrel an hour after penetrating the lime about 115 feet, and that water was found in the gray lime. The Sinclair well, which have been following rather closely down there, reports very little water in the Bend, and also the Partridge well, which is now drilling.

Mr. Fuller: I should like to call attention to the distribution of the wells which have been mentioned, because unless one knows the locations one is likely to obtain a false idea of their bearing on the water problem.

Every well which has been mentioned, I think, except the

Rogers well, has been in an area which I classed as water bearing, and which I believe, is practically universally acknowledged to be water bearing in the Bend. The occurrance of water in the Black Lime in the Rogers well was previously unknown to me. In connection with the problem under discussion, I may mention a few Bend wells on the high part of the Arch which are said to have water. In Fincher No. 1, in the Breckenridge pool, water was reported in the Black Lime at 3490 feet. In the Bobo well, in southeastern Stephens County, water was reported at 3350 feet. In the Cooper well, at Ranger, water was reported at 3178 feet. In the Jackson well, in eastern Stephens County, at 3675feet. Water has been reported in the Black Brother's well in northern Stephens County, but I have not the figures as to depth. The T. P. Carey well, in the same county, is said to have had water at 3745 feet, and water was also found in the Webb well of the Magnolia Company, four miles southwest of Ranger, at 3672 feet.

Mr. Pepperberg: The Jackson well filled up about 1000 feet in ten hours at 1400 feet. They continued to drill in that well to close to 4000 feet, and I made several visits there myself. This well has been shot three times, and with each shot the water has increased. And it might be mentioned that that well is located at a place where the syncline shows at the surface.

Mr. Fuller: That particular well is exactly on the line between the supposed dry and supposed wet, and the observation is therefore very pertinent at this time.

Mr. Taff: In line with what was said yesterday in regard to the geologist keeping close to the driller, I would like to say a word. Now in the Pacific Coast Region, beginning ten or twelve years ago, one large organization established a rule of placing resident geologists in the field, on the ground in touch with every well that is drilling, and when any test is made he is on the job and knows what is done. In the meantime he is in touch with the driller and is on good terms with him, and the driller will tell him the truth if he will tell the truth at all. And in the end you do not depend on the word of the driller as to what you have encountered in your well, not alone the strata but in regard to the water situation. You understand, as it has been brought out here, two men, the driller and the tool dresser, on the same

job can have different opinions. Now if you have a resident geologist on the ground in touch with these men from beginning to end, he can weed out the facts and come to a conclusion if anybody can, in regard to the position of the water and oil bearing strata. In that way you will be able to control and to have a clear understanding as to what you are doing; otherwise you will discuss the matter next year and in succeeding years as you have discussed it today, in regard to the water problem or any other problem in connection with the driller. It is our opinion that it is altogether profitable to have a geologist on the ground in touch at all times with the drilling operations. If you have but one pioneer well, place a man there and let him stay there. It will pay you to let him stay on the job and when the driller encounters water, he will know the position of the water above your oil.

If it is original water, not let in from other wells, you should have an analysis made as a standard of comparison with water from other wells drilled later in the vicinity. By this means you will be able to correlate your water zones and to protect the oil sands from water invasion.

Mr. J. C. White: Mr. Fuller just spoke of some water being in the Bend formation or in the sand just above it. I know there has been some question as to whether it was coming from the Strawn or coming from the Bend. If Mr. Plummer doesn't mind, I would like for him to tell us whether they have any water in the Bend Formation.

Mr. Plummer: The Goode well has about two barrels an hour at 3650 feet in the Bend Formation.

A REVIEW OF THE DEVELOPMENT IN THE NEW CENTRAL TEXAS OIL FIELDS DURING 1918.

By W. G. Matteson, *Ft. Worth, Texas*

INTRODUCTION

Nearly a year and a half ago on October 25, 1917, the J. H. McClesky well of the Texas and Pacific Coal Company near the town of Ranger was drilled in with an initial production of 1,200 barrels and opened up what is destined to be one of the world's greatest oil producing areas. Previous to that time, central Texas had attracted but little attention as prospective oil territory. The Texas and Pacific Coal Company, while prospecting for coal with the diamond drill several years before, had encountered oil at a shallow depth in the Strawn formation of the Pennsylvanian and had subsequently developed the shallow Strawn pool in the extreme southwestern part of Palo Pinto County. Some of the wells at Strawn came in with initial productions of 75-100 barrels daily, but soon settled down to pumpers of 5-25 barrels daily capacity. The field proved rather spotted in character also, resulting in the drilling of many dry holes and so the experience in this region had a strong tendency, to discourage wildcatting in contiguous areas.

History.—The history of the present development in central Texas, however, did not actually begin with the drilling of the discovery well at Ranger. Some three years previously the Texas Company had geologists examining and studying structural conditions in the vicinity of Breckenridge, Stephens County. The result was the location and drilling of the original Parks well. This well found good production at the contact of the "Black Lime" and Smithwick shale of the Bend series of Mississippian age, but owing to the lack of storage and transportation facilities, it was pinched in to 250 barrels daily, which production it is still maintaining after twenty months. The Parks well was thus the first well to indicate the possibilities of the Middle Bend as an oil horizon and it was the knowledge of this fact which gave W. K.

Gordon, of the Texas & Pacific Coal Company, such confidence that he insisted on thoroughly prospecting this deep-lying formation before abandoning the work at Ranger.

The advent of a 1,200-barrel well is generally sufficient to cause a rush toward that vicinity and while a considerable number of oil men were attracted to Ranger, a great many also failed to regard the development seriously and adopted an attitude of watchful waiting. The writer can recall the time when acreage two or three miles from the McClesky well could be purchased for \$50 to \$75 per acre, the same tracts a few months later commanding \$800 to \$1,500 per acre. The successful drilling of several additional wells, nearly all of smaller producing capacity than the McClesky, but extending over a mile or more of territory, was necessary to convince the oil fraternity in general that this new producing horizon in the Mississippian had wonderful possibilities. Shortly afterward, the bringing in of the famous Brewer well with an initial production of 2,200 barrels and the Jones well with an initial production of 4,500 barrels daily removed all remaining doubt about Ranger being a great oil field in the making.

The results of the drilling of the McClesky discovery well and its offset, the Davenport, immediately stimulated geological investigation which quickly assumed extensive proportions. Eastland, Stephens, Brown, Young, Comanche, Shackelford, Throckmorton, Coleman, San Saba, Mills and McCulloch Counties were carefully surveyed and, as a result, additional fields of great promise were found in Stephens County to the extreme north, in central Stephens County close to the towns of Breckenridge and Caddo, in southeastern Stephens County around the Veale well, in eastern Eastland County in the vicinity of the Allen ranch, and in the extreme northeastern part of Comanche County near the town of DeLeon. These fields have been designated as the Black brothers development, the Breckenridge, Caddo and Veale pools, the Allen pool, and the Duke or Comanche County field.

Areal Distribution.—If an irregular line is drawn to encompass the extreme outside producing wells at Ranger, this line at present would enclose an area of approximately 25 square miles. All of this 25 square miles may be termed probable producing

area and will eventually be drilled. At least 75-80 per cent. of it should prove productive. The Whitson well, about 2 miles north of the town, and the Brashear No. 1 of McAlister et al., 5 miles south of town, define the present limits of the pool in a north-south direction. The W. L. McClesky well 1½ miles slightly north of east of Ranger, and the Roper well, 3½ miles west of the town, prescribe the limits of present production in an east-west direction. On January 1, 1919, about 50 producing wells were yielding 31,000 barrels of oil daily, making an average of nearly 600 barrels to the well; approximately 20 wells were shut down on top of the sand awaiting storage, 50 wells were drilling below 3,300 feet and 80 additional wells were rigging up or drilling.

Of the fields in Stephens County, the Breckenridge pool 4½ miles south of the town of Breckenridge has the most promising outlook at present. While this area may be said to be an outgrowth of the development around the original Parks well, previously mentioned, an intense drilling campaign was not commenced until some time after the Ranger discovery, so the real development was actually the result of that at Ranger. That portion of the Breckenridge pool which is being most intensively prospected at present covers an area of 4½x2½ miles in a N. 60 W. direction. Within this area are ten producing wells, the most important of which are the Lauderdale, Fincher No 2, Davis and Brooks. The Lauderdale came in with an initial production of 1,000 barrels while the Fincher No. 2 of the Gulf Production Company made 2,200 barrels daily one week after being drilled in. There are now 44 locations or wells drilling in the vicinity of the Breckenridge pool. This development covers an area of 10x4 miles in a northwesterly-southeasterly direction and will undoubtedly define the limits of the field.

The Caddo field begins at the town of Caddo, 12 miles almost due east of Breckenridge, and extends from the town in a southwesterly direction. The most active development covers an area 3x3½ miles. The pool has 5 producing oil wells, 2 gas wells, and 2 dry holes. On January 1, 1919, there were 30 new locations or wells drilling. The Sandidge well of the Texas Company, which was drilled in several months previously, focused

attention on this area. This well had an initial production of 1,000 barrels and on January first of this year, it was yielding 950 barrels daily.

The Veale pool centers around the Veale well of the Texas & Pacific Coal, Oil & Gas Company, 9 miles south of Caddo. This well was drilled to 3,992 feet. A 20-foot gas sand was found at 3,960 feet which yielded several million cubic feet of gas and a little oil. The oil production has gradually increased until the well is yielding 500 barrels daily at the present time. The only other producing well in this pool on January first was the Sudderth, 2 miles west of the Veale. There were four producing gas wells, and 28 locations or wells drilling in this pool the first of the year. These tests cover an area of 50 square miles around the Veale well as a center.

The Black brothers well, 4½ miles east and 12 miles north of the town of Breckenridge has probably opened a new pool in Stephens County. This well struck oil in the Smithwick shale and has been rated as a 200-barrel producer. It is being drilled to the top of the "Black Lime" where the big production in the Breckenridge district is obtained.

The Allen pool several miles to the east of Ranger, in Eastland County, has received less development work than any area of promise. This is probably due to the fact that two companies, the Sun and the Texas & Pacific Coal, Oil & Gas Company, control the biggest part of the acreage in this vicinity. The Allen well was drilled to the top of the Ranger sand where the tools were lost and never recovered. With the sand just penetrated at 3,037 feet, the well has been making 300 barrels daily, of which 50 per cent is oil and 50 per cent salt water. The offset to this well is now being drilled. Although the development of this field to date has failed to establish the presence of a pool beyond doubt, the future of the area looks very promising, since the territory is covered by one of the largest and best defined structures in the Pennsylvanian of Texas. This structure extends over into northwestern Erath County.

The Duke or Comanche County field is the latest area to be added to the producing column. The Duke or discovery well was drilled to the top of the pay sand in the Marble Falls or

"Black Lime" on September 2, 1918. The drill had just penetrated the top of the sand when a strong flow of gas ignited and burned down the rig, leaving the tools in the hole from which they have never been recovered. Without having ever been drilled in, the well has made 300 barrels daily. Recently the Knowles well, an offset to the Duke, reached the top of the pay sand and made 1,000 barrels a day. Later when this well was drilled in, it made 4,500 barrels daily. Shortly thereafter, the Joe Duke well, another offset to the original well of the field, reached the top of the sand and was reported making 1,000 barrels daily without having been drilled in.

Although these wells are the only producers in this area to date (January, 1919), their capacity indicates that a pool of considerable promise has been found. About 30 wells are now drilling. These wells extend over a 3-mile radius in all directions from the producers and will soon define the limits of the field. The first of these outside wells to reach the sand was the Davis located 3 miles north of the original Duke well in southeastern Eastland County. The Davis well had 65 feet of sand, but was dry, so this test partially limits the extension of the pool in a northerly direction.

Aside from the new fields which have just been briefly outlined, the discovery at Ranger has inaugurated the greatest period of wild-catting the State of Texas has ever known. From Bosque County in the eastern portion to the extreme Trans-Pecos in the west, at least 1,000 tests are being drilled in an attempt to open up additional new oil territory. Grayson, Denton, Tarrant, Bosque, Coryell, Bell, Milam, Lampasas, Hamilton, Erath, Hood, Parker, Wise, Montague, Jack, Young, Archer, Palo Pinto, Brown, Mills, San Saba, McCulloch, Menard, Concho, Coleman, Callahan, Shackelford, Throckmorton, Baylor, Hardeman, Haskell, Jones, Taylor, Runnels, Tom Green, Coke, Nolan, Fisher, Stonewall, Childress, Scurry, Wheeler, Crockett, Terrel and Pecos are some of the counties now being drilled as a result of the central Texas development and the indications for finding additional new fields are promising in some instances.

This constitutes in brief an outline of the history and development of the new Central Texas oil fields to date. The main

purpose of this paper is to present some new and specific information which a year of careful study and investigation has revealed concerning the stratigraphy of central Texas, the structural characteristics of the "Black" or Bend lime formation and its relation to surface flexures, the number and character of the producing horizons, the relation of certain tectonic influences to favorable structural conditions, and the future prospects of the fields already in the process of development as well as favorable and unfavorable territory for future investigation.

Stratigraphy.

The various formations outcropping in central Texas or penetrated by the drill are shown in the following table, beginning with the youngest:

Lower Cretaceous Formations.

These formations, principally the Trinity sands, Glen Rose limestone, Paluxy sand and Comanche Peak limestone, occur partly as outliers. They also form a high and prominent escarpment defining the eastern limit of the Pennsylvanian outcrops passing through western Mills, Hamilton, eastern Brown, western Comanche, western Erath, western Parker, eastern Wise and Montague Counties. A great unconformity separates the lowest member of the Lower Cretaceous from the underlying Permian or Pennsylvanian rocks, denoting a big hiatus. The Permian and Pennsylvanian formations dip normally west to N. 50 W., while the Cretaceous formations dip normally east to S. 50 E. The deposition of the Permian was followed by the withdrawal of the Permian sea and a general uplift of the strata as a result of the Appalachian revolution. This period was followed by one of great erosion wherein the Permian and Pennsylvanian formations were nearly reduced to a peneplain upon which the Lower Cretaceous strata were deposited. As a result of this stratigraphic relationship, favorable structure in the underlying Permian and Pennsylvanian rocks may very often have no reflection or indication in the overlying Cretaceous formations. The writer has examined thousands of square miles of Cretaceous covered are wherein the strata have shown either a normal southeasterly dip or else lie almost flat; yet there is little

System	Series	Formation	Description	Thickness
Cretaceous	Lower Cretaceous	Trinity, Comanche Peak, etc.	Red to white sands, clays, chalky, marly limestone, etc.	Varying
-Unconformity-	-Unconformity-	—Unconformity—	Unconformity	
Carboniferous.	Permian	Double Mountain	Scarlet to gray clays, shales, sands and sandstones. Salt and gypsum.	1,800-2,000 feet
		Clear Fork	Deep red to gray sands, sandstones, clays, some limestone and gypsum.	1,500-1,800 feet
		Wichita-Albany	Deep red clays, shales and sands, largely. Albany beds are thin bedded limestones with alternating red to gray clays and shales.	1,000-1,500 feet
	Pennsylvanian	Cisco	Red to brown sandstones, gray to red shales and clays, sandy limestones, coal.	800-1,000 feet
		Canyon	Thin to thick bedded, tabular to lenticular, gray limestones with alternating beds of gray to blue clays. Alsa some sands.	8001,100 feet
	-Unconformity-	Local Unconfor'ty.	Local Unconformity	
		Strawn	Conglomerates, red sandstones and clays, blue to black shales, gray to blue limestones.	1,500-2,500 feet
		—Unconformity—	Unconformity	
	Mississippian	Smithwick Shale (Upper Bend)	Largely blue to black shales, often carboniferous, with some sand and little gray to black line.	300-500 feet
		—Disconformity—	Disconformity	
		Marble Falls, Bend or "Black Lime"	Gray to black, compact, finely crystalline limestone, blue to black shales, sands.	100-900 feet
		Lower Bend	Black shale, often very bituminous, also some black lime.	75-125 feet
	-Unconformity-	—Unconformity—	Unconformity	
	Cambro-Ordovician	Ellenberger Limestone	Largely gray to white, massive, crystalline limestone.	100-1,000 feet

doubt that these formations somewhere conceal favorable structure in the underlying Permian and Pennsylvanian which might contain oil in commercial quantity. The lower Cretaceous in central Texas is not absolutely devoid of structure, however, and naturally the question arises—will such structures continue into the underlying Permian and Pennsylvanian? It is the opinion of the writer that in a good majority of the occurrences, these Cretaceous flexures will be found to be the result of post-Cretaceous folding along old Permian and Pennsylvanian flexures in which case the Cretaceous arches will be a reflection of structure in the underlying Permian and Pennsylvanian formations and likewise these latter flexures, in turn, might be indicative of structure in the Bend or Mississippian.

Permian Formations.

The Double Mountain Formation of a maximum thickness of 2,000 feet is the youngest of the Permian series. In Oklahoma, its upper part has been called the Greer and the lower part the Quartermaster formation. It consists of deep to scarlet red clays, shales, sandstones, sands and sandy shales, thin beds of limestone and dolomite, bluish clays and shales, and thick beds of massive gypsum and rock salt. This formation outcrops in an area of some 20,000 square miles between Hall and Wilbarger Counties to the north, and Reagen and Tom Green Counties to the south.

The Clear Fork Formation has a maximum thickness of 1,800 feet. It forms part of the red beds and lithologically is very similar to the Double Mountain formation, excepting it does not contain so much gypsum and practically no salt. It outcrops in Wilbarger, Baylor, Throckmorton, Haskell, Jones and Shackelford Counties.

Wichita and Albany Formations.—The Wichita formation varies from 1,000 to 1,500 feet in thickness and consists of red clays, sometimes concretionary, red, blue, and grayish-white sandstones, and occasional blue shales. It outcrops in Clay, Wichita, Baylor, Wilbarger, Archer, Young and Throckmorton Counties. Farther to the south and southwest, it is believed to grade imperceptibly into the Albany formation which consists

predominatingly of thin-bedded, white to gray limestones with alternating marly, reddish to bluish clays. The thin-bedded limestones become more massive near the top of the formation which outcrops prominently in Mills, McCulloch, Concho, Runnels, Coleman, Young, Baylor, Throckmorton and Shackelford Counties. The Wichita-Albany beds constitute the lowest Permian formation and rest conformably upon the underlying Pennsylvanian formations, whereas in Southern Oklahoma, the Permian is uncomformable with the underlying Pennsylvanian over considerable area.

The Pennsylvanian Series.

The Cisco Formation constitutes the upper division of the Pennsylvanian in central Texas and consists of 800 to 1,000 feet of red to blue clays or shales, red to gray sandstones, red, conglomeratic sandstones, and occasional thin beds or arenaceous limestone. North of Stephens County, the shales and sandstones are predominatingly red in color and the limestones are generally absent. South of the Stephens-Young County boundary, the gray shales and sandstones predominate in a number of localities and thin to massive beds of limestone are not uncommon, especially in Brown County. This formation contains some coal seams of a commercial value in Young County and its sands yield oil in prolific quantity from the deep wells at Electra and Burkburnett. The unusual amount of wildcatting in the red bed belt of the Texas Permian to the west of the Cisco outcrop is influenced largely by the strong probability of opening up another pool in the same horizon of the Cisco as that yielding the oil in north Texas, provided satisfactory structural conditions are obtained. The Cisco forms a broad stretch of outcrop extending in a general N. 30 E. direction from McCulloch County to the Red River through the counties of Brown and Coleman, Callahan, Shackelford, Stephens, Eastland, Young, Jack, Archer, Clay and Montague.

The Canyon Formation varies from 800 to 1,100 feet in thickness and consists largely of tabular, thin to heavy bedded, gray to white, crystalline limestone, highly fossiliferous, and alternating beds of gray to blue clay and shale. The limestone exposes a rough, gray, sandy surface on weathering. Occasion-

ally red sandstone and conglomerates are observed as well as red clays. More sandstone and correspondingly less limestone is encountered to the north.

The Canyon is overlain conformably by the Cisco, but a pronounced unconformity separates it in some areas from the underlying Strawn beds. This unconformity[1] may be of a local nature only but is most marked in some areas, especially at Ranger. By reference to some of the well logs accompanying this paper, it may be observed that the thickness of the Canyon in the Jack Phillips well is 445 feet, in the J. H. McClesky well 580 feet, in the S. V. Davis well 825 feet, in the Jones well 974 feet, and in the Slayden No. 1, 980 feet. The surface elevations of these wells are as follows: Phillips 1,509, McClesky 1,515, Davis 1,445, Jones 1,563, Slayden 1,526. In the vicinity of Ranger, the Canyon has a general strike of N. 30 E. and an average dip of 40 feet per mile N. 60 W. The maximum dip of the Canyon here is only 60 feet per mile. A line bearing N. 30 E. through the J. H. McClesky well, will pass approximately 1 mile to the east of the Jones well. With an allowance of 100 feet for the difference in elevation and the dip of the formation between the Jones and McClesky wells, there is still a thickening of 294 feet in the Canyon in a mile which can only be reasonably accounted for on the basis of an unconformity. The Davis well lies 1½ miles slightly north of east of Ranger, the McClesky well 1 mile S. 30-40 W. of Ranger, and the Phillips well 2¼ miles S. 50 E. of the McClesky well or if a line bearing S. 30 W. representing the approximate strike of the Canyon beds were projected from the Davis well, this line would lie between the Phillips and McClesky wells, yet the Davis well has a lower elevation and 825 feet of Canyon as compared to 445 feet in the Phillips and 580 feet in the McClesky well. These facts seem to establish the presence of an unconformity beyond much doubt.

The Canyon outcrops in McCulloch, Brown, Eastland, Stephens, Palo Pinto, Jack and Wise Counties.

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[1]Since this paper was written additional field work covering Brown County has demonstrated conclusively that the unconformity between the Canyon and Strawn occurs over a wide range of territory and is probably general in character.

Strawn Formation.—Early attention was attracted to the Strawn series on account of the finding of minable coal seams in it near the towns of Thurber and Strawn. This formation varies in thickness from 500 feet in southwestern Brown County to 2,500 feet in the vicinity of Strawn. The greatest thickness is 4,000 feet.

The Strawn consists largely of rusty, red sandstones, sands, shales, clays and conglomerates, blue to black shales, and some few beds of limestone. The greater portion of the formation is clay or shale. It has been subdivided into the upper, middle and lower Strawn, the middle beds being petroliferous and yielding shallow, productive oil wells near Strawn in Palo Pinto County, Ranger and Eastland in Eastland County, and Breckenridge and Caddo in Stephens County, also, at Lohm in McCulloch County. It outcrops conspicuously in Mills, San Saba, northwestern Lampasas, Brown, Eastland, Comanche, Erath, Palo Pinto, Parker and Jack Counties.

The Bend Series.

The Smithwick Shale consists principally of black, carbonaceous shales with sand lentils. Blue shales and dark limestones are also found. The formation varies from 200 to 600 feet in thickness with an average thickness of 450 feet. A study of the Smithwick-Strawn contact reveals a marked unconformity separating these two formations. This is substantiated by the examination of well logs which show a variation in the thickness of the Smithwick of 200 to 300 feet in a mile in some areas. The sandstone lentils in this formation have yielded considerable gas and small quantities of oil. The Gray well in Coleman County, the first productive horizon in the Black brothers well of the Texas Company in northern Stephens County, the Chestnut well in Palo Pinto County, and the gas in the Allen well in eastern Eastland County are all producing from the Smithwick.

The Smithwick shale has been classified by Sidney Paige[1] as part of the Bend formation of Mississippian age. There has been a tendency to view this correlation with doubt, some inves-

[1]Llano-Burnet Folio, No. 183, Geologic Atlas of the United States, by Sidney Paige.

tigators contending that part of the Smithwick is of Pennsylvanian age. R. B. Dudley, of Mineral Wells, has recently found some fossils in the Smithwick, however, which are undoubtedly Mississippian. Ulrich has stated personally that he believes the Smithwick to be Upper Bend or Mississippian. C. L. Baker, formerly associated with the Bureau of Economic Geology of the State University of Texas, collected some fossiles from an outcrop of Marble Falls limestone along the Colorado River near the town of Bend. These fossils were sent to Dr. Stuart Weller, who stated that they were new forms but unquestionably of Mississippian age. Thus the evidence seems rather conclusive that the Smithwick shale and the underlying formation, the Marble Falls limestone, are older than the Pennsylvanian. The accumulation of oil in great quantity at the contact of the underlying "Black Lime" or Marble Falls limestone with the basal Smithwick indicates the presence of a disconformity or possibly an unconformity.

The Smithwick shale outcrops in a narrow belt around the Llano Burnet uplift, more especially in San Saba County.

The Marble Falls Limestone or "Black Lime" Formation derives its name from a prominent outcrop of the same near the town of Marble Falls in Burnet County. It consists of black to gray limestone with alternating beds of black to blue shale. Some sandstones, more or less lenticular, and a little white lime are also found. Since attention has been so widely attracted to this formation since the discovery of oil within it at Ranger, it has been variously designated as the "Black Lime" or "Bend Lime," and from fossils found within the same, its age has been definitely established as Mississippian.

The Marble Falls limestone varies from about 100 feet in thickness as shown by the log of the Cummings well of the Coline Oil Company near the town of Locker in San Saba County and by the log of the Abney well of Graham, Thomas and Ludlow 8 miles south of Brownwood to 970 feet in the Alvis well of the Oil State Petroleum Company 2½ miles north of Grosvenor in Brown County. At Ranger, the thickness of this formation varies from 400 to 600 feet.

It is this formation which has recently yielded such prolific production in central Texas. It outcrops in a narrow belt near

the southeastern part of the Burnet quadrangle, northeast of Bluffton, in the Riley Mountains in San Saba County, and in several places along the upper San Saba River, the Colorado River and the Pedernales River.

Lower Bend Shale.—Near the bottom of the Bend series, immediately overlying the white to gray, crystalline Ellenberger limestone is a formation, 50-100 feet in thickness, composed largely of black, bituminous shale with some few strata of gray to black limestone. Udden[1] has named this specific unit of the Bend the lower Bend shale. This formation is often absent from the Bend series.

Cambro-Ordovician Series.

The Ellenberger Limestone Formation consists of a massive white to gray, crystalline, dolomitic limestone, 100 to 1,000 feet in thickness. Thin beds of sand or sandstone may be found near the top of the formation. Near San Saba the Ellenberger limestone has been metamorphosed into marble, which has been used in the South for interior decoration.

The lower Bend shale directly overlies the Ellenberger limestone, a great unconformity separating these two formations. When the Ellenberger is penetrated by the drill in prospecting for oil, the test is generally abandoned if no commercially productive horizon has been encountered above. Graham, Ludlow and Thomas in their Abney No. 1, 8 miles south of Brownwood, drilled entirely through the Ellenberger nearly to the bottom of the Hickory sandstone, overlying the pre-Cambrian shists, without favorable result. A study of this most interesting and valuable log shows the folowing formations to have been penetrated.

0- 150 feet	Glen Rose limestone	Lower Cretaceous.
150- 250 feet	Trinity sands	
250-1,060 feet	Strawn formation	Pennsylvanian.
1,060-1,420 feet	Smithwick shale	Mississippian.
1,420-1,510 feet	Marble Falls or "Black Lime"	
1,510-2,100 feet	Ellenberger limestone	Cambro-Ordovisian.
2,100-2,600 feet	Wilberns and Cap Mountain formations, and Hickory sandstone	Cambrian.

[1]"Review of the Geology of Texas," by J. A. Udden, C. L. Baker, and Emil Bose. Bulletin 44 of the University of Texas, page 42.

Structural Geology.

Surface Structure Type.—After eastern geologists, employed by the Texas & Pacific Coal Company, had made a careful examination of the Ranger field, prior to its discovery, they advised against expending the necessary funds to prospect the territory on two general principles, viz., the absence of what in their mind constituted favorable structure and the failure of past development to discover any sufficiently prolific and otherwise satisfactory producing horizon. The Strawn sands were of a spotted, erratic character, capable of yielding only small wells, while the Parks development in Stephens County was more or less of an unknown quantity.

A detailed survey at Ranger revealed very slight surface structure in the form of a combination nose and terrace with only eight feet of closure in the vicinity of the Walker well. Past experience had proved that such structures, themselves, possessed the most meager possibilities, sometimes yielding small pumping wells, but more often being barren altogether. If the eastern geologists entertained the possibility of such slight structure as at Ranger being indicative of larger and more pronounced structure in the Bend or Mississippian formations, and that in these formations, oil sands of commercial value might be found, they evidently concluded the chances for such an unusual combination of favorable features to be so largely problematical as not to warrant serious consideration. Yet this is precisely what the discovery at Ranger revealed, namely that slight surface wrinkles, noses, terraces, etc., of small areal extent, which in themselves offered no commercial possibilities, might be indicative of very pronounced, extensive and favorable structural conditions in the Bend or Mississippian which in part was very bituminous in character and actually possessed prolific oil-bearing sands. Since then, actual development of such wrinkles, noses and terraces over several counties has yielded either oil or gas in commercial quantity from the Mississippian formations in 70 per cent. of the attempts, while many of the recorded failures were the direct result of the pinching or complete absence of the sand.

Relation between Surface and Sub-Surface Structure.—It is important therefore, to ascertain the relationship of these sur-

face wrinkles to the underground structure, and in such an investigation, the value of accurate well logs is inestimable. Development which will give any accurate, detailed information of this character has proceeded sufficiently far in only one locality—Ranger,[1] where a careful study has revealed the following:

1. The sub-surface structure is many times greater in areal extent than the surface structure.

2. The sub-surface structure is much more pronounced than the surface structure.

3. The axis of the surface structure does not coincide with that of the sub-surface, the axis of the latter being a considerable distance to one side of the former.

4. As a result of the greater lateral extent of the sub-surface structure, the best part of such structure yielding the largest producers may be found underlying absolutely no surface structure whatsoever.

5. The west and northwest side of the sub-surface structure yields the largest producing wells.

6. The thickness and porosity of the sand is of equal, if not greater, importance as structure. Where the sand pinches or thins or is cemented, dry holes will be drilled on structurally favorable locations.

7. The direction of the dip of the sub-surface structure may be entirely opposite to the surface dip of the same area projected. In fact, the character of the surface dip may be no indication whatsoever of the character of the dip on the sub-surface structure.

8. The main axis of the sub-surface structure as a whole is in the general direction of the axis of the Bend arch which corresponds closely to the strike of the surface formations. Due to cross folding, one or several minor axes may develop along which larger producing wells may be found than in the vicinity of the main axis.

9. Localization of production is the direct result of cross folds superimposed upon the secondary folding parallel approximately

[1]The development in the Breckenridge field has now reached the stage where the relation of surface to sub-surface structure can be accurately ascertained.

to the axis of the main Bend arch. The axes of cross folding have a northwest-southeast trend and the complete resultant structure is very complicated due to the intensity of cross folding.

Details of Structural Conditions at Ranger.—While a sufficient number of wells extending over a wide area have been drilled to the top of the sand at Ranger to permit some considerable outline and definition of the structure from which fairly reliable and accurate conclusions may be drawn, development work has not proceeded to that degree to permit any considerable detailing of the structure. The contouring of the structure to date from nearly 100 well logs indicates that the longest and probably the main axis trends north-northeasterly, passing close to the Jones well and the H. Brashear well of McAlister et al. This axis is curving and locally may bear slightly northwest. From a contour map of the surface structure, the Walker No. 1 of the Texas & Pacific Coal, Oil & Gas Company was located on the small closure previously mentioned yet the Walker well is actually 85 feet down the dip on the southeast or reverse side of the sub-surface structure in the Bend. The Jones No. 1 of the Humble Oil & Refining Company on the surface is situated well down the side of the nose and terrace in the vicinity of a west to southwest dip, yet the Jones is found to be practically on the highest point of the sub-surface structure close to the main axis. To the east of the Jones well, the sub-surface arch shows a strong southeasterly dip and to the west a heavy northwesterly dip—a marked divergence from surface conditions. Likewise in the vicinity of the Hagaman No. 1 of the Lone Star Gas Company east of Ranger, the surface shows a strong, normal northwest dip of 60 feet per mile while the sub-surface structure shows the dip to be changing from southeast to south to southwest and dipping at the rate of 200 feet per mile. From the Jones No. 1 to the Shook No. 1 to the southeast which latter well defines the easterly extent of production in this vicinity, there is a southeasterly reverse dip of 160 feet in 8,000 feet or a drop of 5 feet in every hundred. The McClesky discovery well is located on the easterly or reverse side of the sub-surface structure and 100 feet down the dip from the axis which explains why subsequent wells farther west proved bigger producers. To date, the Brashear well of McAlister et al. is the highest point struc-

turally on the anticline, being 25 feet higher than the Jones well. The contouring at present, while incomplete, indicates that these two wells are the centers of two domes along the main axis. The performance of the Brashear in yielding a large quantity of gas before producing much oil is now readily understandable. The same applies to the Duffer wells of the Texas Company just to the south of the Jones wells.

Whereas production on the east side of the structure has extended 160 feet down the dip where the sand condition has been regular before being limited by a series of dry holes, the production on the west side of the structure is found at least 235 feet down the dip in the case of the Butler No. 1 of the Texas & Pacific Coal, Oil & Gas Company and will probably extend 300 feet down the dip at least since the Roper well is rated as a good producer and is located nearly three fourths of a mile west of the Butler.

The development of so many wells of large capacity three to four miles west and northwest of Ranger has led to the belief that the main trend of the Ranger anticline is in a northwesterly-southeasterly direction. There is practically no evidence to date to support this contention, which is far from logical. Considering the character of the orogenic forces which produced the Bend arch, it is but natural to expect that the minor or secondary folding which accompanied or was subsequent to this movement would occur along lines somewhat parallel to the axis of the main uplift which was in a direction approximately N. 30 E. Subsequently secondary cross folding would result in specific localization of structural conditions exceptionally favorable for the accumulation of oil. Of course it is possible for the cross folding to have been of such magnitude as to make the axis of such folding the main and longer axis of the structure as at Caddo, La., but the projection and study of the sub-surface structure at Ranger up to the present time has revealed no evidence of this nature, every indication pointing to the longer or main axis extending in a general N. 20-40 E. direction with the axis of the cross folds nearly at right angles. The exceptionally strong dip to the west and northwest of the Jones No. 1 offers additional evidence to substantiate this view. There has been considerable speculation as to just how far to the west and southwest and

down the dip production would extend at Ranger and although the Holcomb No. 1 of the Cosden Oil & Gas Company just east of Eastland and the Benedum & Trees well a short distance south of Eastland are practically dry holes in the Marble Falls limestone, this question has not been settled since these dry holes were the result mainly of the pinching or total absence of sands.

A number of small surface structures have been worked out in detail in the area north of the town of Eastland, suggesting the possibility of another large fold in the Bend with an axis approximately paralleling the axis of the Ranger anticline. This tentative view conforms with the element of probability more than the attempt to explain any production which might be obtained in the future north of Eastland as due to an extension of the Ranger structure. The number of wells now drilling north of Eastland will shortly indicate if another large fold is there present. If such should be the case and a porous sand of average thickness is penetrated, yielding production, it would not be surprising to see production bridge over any synclinal basin between the folds, giving an area of continuous production from Ranger to a point several miles north of Eastland.

It is most significant that practically no salt water[1] has been encountered in the sands of the Marble Falls or "Black Lime." There is a considerable synclinal basin between the town of Ranger and the Davis, Vick and Phillips wells to the east. Several dry holes have been drilled in this syncline showing as much as 30 feet of sand without encountering any salt water. Salt water in quantity was found in the Allen well on the structure seven miles slightly south of east of Ranger, however No satisfactory explanation has been advanced to date to account for this absence of salt water,[2] but it is most gratifying and insures a long life to the wells. This fact also places a much higher value on a well here than at El Dorado where the rapid encroachment of

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[1]Lately salt has been found in a few wells at Ranger.

[2]The general absence of salt water may be due to the lenticular nature of the sands which are found as irregular lenses in shale or lime which are non-water bearing and probably cut off any water from reaching the oil sands.

salt water has ruined some wells, greatly affected the capacity of others, and has caused the operators much anxiety and expense.

There are still large areas in the vicinity of Ranger which are favorably situated structurally, but which have received very little or no development to date. The territory due north of the town for several miles, the region north of the Hagerman wells of the Texas & Pacific Coal, Oil & Gas Company, the Lone Star Gas Company, and the Texas Company, the region east of the Davis, Vick and Phillips wells, and the area north, south, east and west of the H. Brashear well of McAlister et al. is included under this classification. The question of suitable production in the above areas depends directly on the presence of sands of suitable thickness and porosity.

The Brashear well, structurally, is on about the highest part of the Ranger anticline. A study of the accompanying log of this well shows a complete absence of sands in the Marble Falls or "Black Lime" formation. Six to seven million cubic feet of gas was encountered at the contact of the Marble Falls limestone and the Smithwick shale. After this gas was partially exhausted, the well started to make oil and is now producing 300 barrels daily. The Texas & Pacific Brashear No. 1, one mile north, the Prairie Oil & Gas Company's J. T. Falls well, 1¼ miles slightly west of north, the Magnolia Petroleum Company's E. H. Webb No. 1, 2¼ miles north and the Ranger-Duncan Company's Minnie Sibley No. 1, 2¼ miles southeast of the McAlister Brashear are all dry holes for one reason—practically no sands. Thus a considerable area in this vicinity has been partially condemned, but sands of a lenticular nature generally develop suddenly and unexpectedly. It is the opinion of the writer that sands may be found to the southwest and some distance to the south of the Brashear well. This region is certainly worthy of several tests but only big companies with large reserve funds for prospecting are in position to make the gamble.

The logs of the Vick, Berry and Phillips well east of Ranger indicate an arching of the Marble Falls limestone in this vicinity, yet all these wells were practically dry for the same reason—absence of sands. Whether this arch is merely a nose or tongue of the main Ranger structure or the west flank of another fold of

considerable magnitude is a question which can not be satisfactorily answered until more development work is done to the east of these wells. In the vicinity of Hagerman No. 1 of the Texas & Pacific Coal, Oil & Gas Company, the 1,690-foot contour and all contours below it change in strike from a N. 40 E. direction to an easterly direction and thence southwesterly to the S. V. Davis and W. L. McClesky wells of the Texas & Pacific Coal, Oil & Gas Company. There has not been sufficient development work around these wells to indicate whether the contours swing around them and assume a northeastward trend again or swing southward to form a long tongue or nose which envelops the Vick, Phillips and Berry wells. This territory, however, is certainly worthy of more development.

It is the opinion of the writer based on a close study of the region that when development at Ranger has reached a stage where the sub-surface structure can be completely detailed, the structure will be found to consist of one large anticline with two or more closed domes and several prominent noses or fingers extending in all directions like the arms of an octopus as a result of the complicated cross folding of which there are strong indications already.

As a result of the evidence thus presented, the question naturally arises—how much dependence can be placed on surface structure in directing initial developments? The writer believes that the main value of surface structure lies in the fairly well established fact that its presence is generally indicative of structure in the Mississippian or Marble Falls limestone of much greater areal extent and more pronounced character. In making initial locations, there is no other recourse except the surface structure and the development in all the new fields have proved that if initial wells are favorably located with respect to the surface structure, they will come within the producing area of the large sub-surface structure although they will not necessarily be most favorably located with respect to such sub-surface structure. And since the surface structures are generally of very limited areal extent, it is only a question of a very short time, if the initial wells are productive, before intelligent development will have to be guided entirely by a close study of the sub-surface

structure from the evidence presented by carefully kept well logs.

It must also be clearly recognized that some good, highly productive structure may be found in the Bend formations which has no favorable surface expression whatsoever. This is well illustrated by the S. V. Davis and W. L. McClesky wells of the Texas & Pacific Coal, Oil & Gas Company, 1½ miles east of Ranger. In the vicinity of these wells, the Pennsylvanian rocks at the surface show a normal, practically unbroken dip of 60 feet per mile to the northwest, whereas the sub-surface structure in the Marble Falls limestone shows a southerly to southwesterly dip of 200 feet per mile. Prospecting for such blind structure, however, will demand considerable capital and will be successful in only a comparatively few instances. Such prospecting should be deferred until all surface flexures of a favorable nature have been found and investigated.

Likewise, as previously mentioned, owing to the marked unconformity between the Pennsylvanian, Permian and Cretaceous formations and the conditions governing the deposition of the same, areas covered by the Cretaceous rocks will generally show a normal easterly to southeasterly dip or local flattening, and in some few instances will conceal structure in the underlying rocks. Where definite structure is found in the Cretaceous formations, this structure has probably developed in the majority of instances along old lines of folding in the underlying rocks. Hence Cretaceous structure in central Texas in all probability is a surface reflection of underlying structure in the Permian or Pennsylvanian which in turn is generally indicative of structure in the Bend or Mississippian. Such Cretaceous flexures are worthy of a test. The writer knows of only two actually Cretaceous structures in central or northern Texas which have been drilled. The most prominent is located in northern Grayson County, north of Denison and has variously been designated as the Preston anticline, Munson dome, etc. Several wells have been drilled on this structure and have proved beyond question that the structure continues into the underlying Pennsylvanian. These wells have yielded a little gas and a show of oil but none of them were drilled sufficiently deep to test the possibilities of the structure fairly.

Surface Structure in Other Central Texas Fields.—Concerning the area around Breckenridge in Stephens County, several small and closely related wrinkles are observed in the vicinity of the present development. The structure around the Allen well in the extreme eastern part of Eastland County is the largest and best defined of any in central Texas. It extends over into northwestern Erath County and has 30 feet of closure. The structure around the Duke well is the poorest defined of all, but careful geological work established the presence of a reverse dip and the discovery well was located and drilled on this evidence. The Breckenridge, Allen and Duke developments were the direct result of careful geological investigation. Drilling in these areas has not progressed to the point where much detailed information is available concerning the sub-surface structure, but many of the same general conclusions drawn from a close study of the Ranger field will undoubtedly apply.

General Tectonic Relationship.

In order to have a comprehensive knowledge of specific structural conditions and the causes of localization of structures as well as the necessary information to direct the prospecting for new structures in the most favorable territory, it is essential to understand the general structural conditions affecting the various formations of central Texas, the history of the orogenic movements which have established such conditions, and the tectonic relationships which have resulted. Cheney[1] and Hager[2] have called attention to the fact that the Bend or Mississippian formations of central Texas had been folded into a great arch or plunging anticline which extends over several counties, the axis of this arch having a general trend of about N. 20-30 E. and extending from the vicinity of Brady in the south to Graham in Young County in the north.

Stratigraphic History of North Central Texas.—A careful stratigraphic study of the central Texas area indicates that after

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[1]M. G. Cheney, *Oil Trade Journal,* April and May, 1918.

[2]Dorsey Hager, "Geology of the Oil Fields of North Central Texas," Bulletin 138, American Institute of Mining Engineers, 1918.

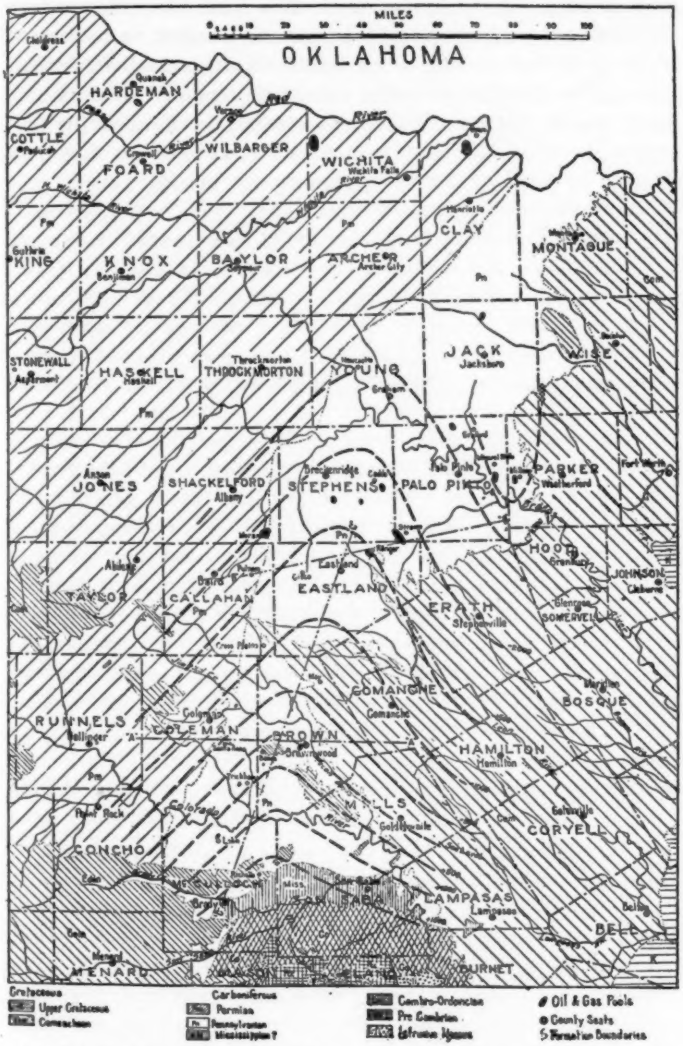

FIG. 5. The Bend Arch. After Hager, Bull. 138, June, 1918. Amer. Inst. Min. Eng.

the deposition of the lower and middle Bend formations, there followed a series of disturbances which resulted in at least a slight uplift and arching of the Middle and Lower Bend formations. The Smithwick shale was then deposited after which more intense orogenic movements occurred, resulting in the formation of what has been termed the Bend arch as shown in Fig. 5. Secondary forces accompanying this movement produced minor, parallel flexures whose axes had a northerly-southerly trend. Subsequently another series of orogenic movements associated with the Wichita-Arbuckle uplift in southern Oklahoma and the Llano-Burnet uplift in central Texas produced a series of cross folds whose axes had a more or less east-west trend. The intersections of the cross folds with the minor north-south flexures have yielded the oil-bearing structures of central Texas.

The magnitude of the Bend uplift was sufficient to cause a general regression of the sea, exposing a great area of the Smithwick shale to erosion. Thus the synclinal basin between the minor north-south flexures received additional accumulations while the anticlinal ridges had considerable of the shale covering removed. In some regions, peneplains may have been formed, but in general, the surface of the Smithwick shale was irregular when submergence again occurred. Upon this surface the Strawn beds were deposited. Well logs prove conclusively that in some regions at least the sea withdrew sufficiently to expose part of the Strawn to considerable erosion before the overlying Canyon formation was deposited.[1] After this hiatus, which may be local in character, deposition was continuous until the end of Permian time when gentler orogenic movements caused a gen-

[1]Detailed work in Brown County has revealed unconformities within the Canyon and Cisco formations indicating progressive folding throughout Pennsylvanian time. It was generally followed by quiescence during which the succeeding strata were deposited in normal condition. That several such cycles have occurred is revealed by field conditions which show limestone beds with normal northwest dip in the Canyon-Cisco underlain by highly arched lower beds showing reverse south and east dip. The importance of this condition was first brought to the writer's attention by Dr. S. L. Galpin.

eral uplift of the area above sea level and superimposed light wrinkles and flexures in many instances in the vicinity of the folds in the underlying Mississippian.

Tectonic Relations of North Central Texas Pools.—Reference to Fig. 6 shows the importance of understanding these tectonic relationships. Thus an axis of a general north-south trend

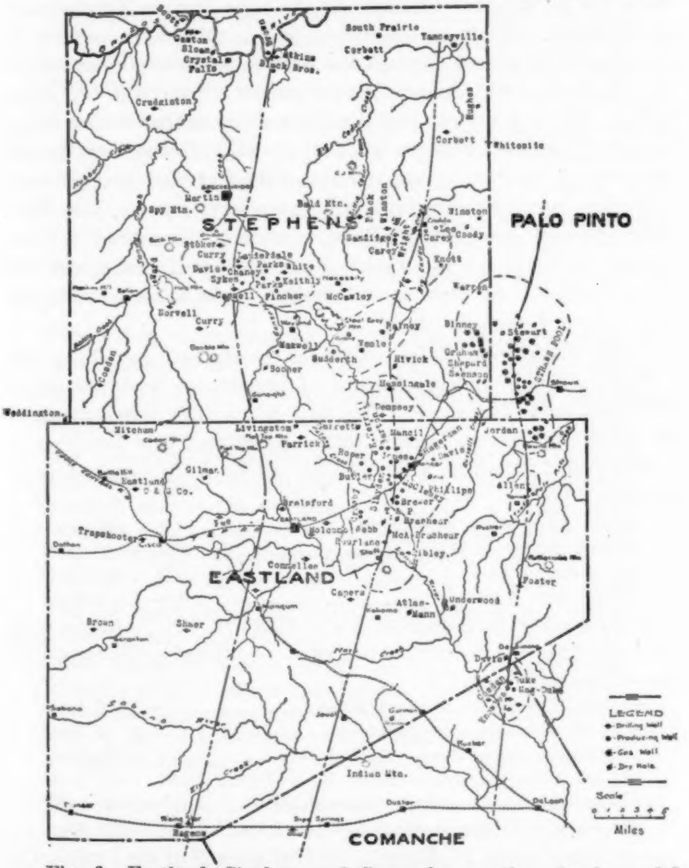

Fig. 6. Eastland, Stephens and Comanche counties, showing axial and tectonic relationship of the various pools. The above dashed outlines of various pools have no relation to surface structure but define approximate area of present development. They may be subsequently altered in detail with future development.

through the Breckenridge pool passes through the Black Brothers development to the north and the development around Eastland to the south. If this axis is projected further to the south, it passes through the structure in the vicinity of the Bailey and Bangs development in Brown County. A similar, parallel axis through Ranger passes through the Veale and Caddo pools to the north in Stephens County and the Sipe Springs development in Comanche County to the south. Still a third axis, parallel to the other two, passes through the Strawn shallow pool in southwestern Palo Pinto County, thence southward through the Allen pool in Eastland County and the Duke development in Comanche County. The area between the Bailey well in Brown County and the town of Eastland in the vicinity of the Eastland-Breckenridge axis thus becomes especially favorable territory for investigation; likewise new pools will be eventually discovered by projecting the axis of the Caddo-Veale-Ranger flexure and the Strawn-Allen-Duke flexure and subjecting the areas traversed to close detailed geologic study.

The Ellenberger Ridge.—Careful correlation of well logs has revealed another general feature of importance with respect to the Ellenberger limestone. The Ball No. 1, five miles north of the town of Myra in Cooke County, penetrated this limestone at a depth of 1,640 feet, a correlation of the formations being as follows:

Lower Cretaceous formations	0— 680 feet.
Strawn formation	680—1,185 feet.
Smithwick shale	1,185—1,640 feet.
Ellenberger limestone	1,640—2,675 feet.

Proceeding in a southwesterly direction, the Winston well near Caddo in Stephens County shows the following formations to have been penetrated:

Canyon formation—Pennsylvanian	0—1,215 feet.
Strawn formation—Pennsylvanian	1,215—2,795 feet.
Smithwick shale—Bend—Mississippian	2,795—3,260 feet.
Marble Falls limestone—Bend—Mississippian	3,260—3,480 feet.
Lower Bend shale—Bend—Mississippian	3,480—3,625 feet.
Ellenberger limestone—Cambro Ordovician	3,625—3,733 feet.

In the vicinity of Ranger, the Phillips well of the Prairie Oil & Gas Co., the Crosby & Davis well, the Brashear well of McAlister et al., the J. T. Falls well of the Prairie Oil & Gas Co., the Dean well of the Sammies Oil Co., the Webb well of the

Magnolia Petroleum Co., the Holcomb well of the Cosden Oil & Gas Co., and two or three other wells have penetrated the Ellenberger formation. The logs of the Brashear and Phillips wells are presented in detail elsewhere in this paper. The following formations were found in the Dean well close to the town of Ranger:

Canyon formation—Pennslyvanian	0— 905 feet.
Strawn formation—Pennsylvanian	905—2,620 feet.
Smithwick shale—Bend—Mississippian	2,620—3,178 feet.
Marble Falls limestone—Bend—Mississippian	3,178—3,603 feet.
Ellenberger limestone—Cambro—Ordovician	3,603—3,709 feet.

Several wells have been drilled into the Ellenberger in Brown County among which are the Alvis No. 1 of the Oil State Petroleum Co., north of Grosvenor, the Bartles and Duminel well north of Brownwood, the Abney No. 1 of Graham, Thomas and Ludlow, eight miles south of Brownwood, and the Matlock No. 1, a few miles east of Brownwood. The logs of several of these wells have already been given.

Proceeding southwestward to the Trickham oil field in southeastern Coleman County and the log of the Producers Oil Co., Guthrie No. 1 shows the following formations to have been penetrated:

Cisco formation—Pennsylvanian	0—162 feet.
Canyon formation—Pennsylvanian	162— 912 feet.
Strawn formation—Pennsylvanian	912—1,236 feet.
Smithwick shale—Bend—Mississippian	1,236—1,585 feet.
(Possibly a little Marble Falls in above.)	
Ellenberger limestone—Cambro—Ordovician	3,663—3,709 feet.

The log summary of the Dallas-Milburn well in northeastern McCulloch County is as follows:

Strawn formation—Pennsylvanian	0— 668 feet.
Smithwick shale—Bend—Mississippian	668— 947 feet.
Ellenberger limestone—Cambro-Ordovician	947—2,266 feet.
Wilberns, Cap Mts., and Hickory sandstone formations—Cambrian	2,266—2,525 feet.

The Cawyer No. 1 of Burford and Brim situated about three miles slightly west of south of the Dallas-Milburn well in McCullock County showed a similar condition, namely 260 feet of Smithwick shale lying directly upon the Ellenberger limestone with the Marble Falls lime completely missing. Finally the Cum-

mings No. 1 of the Coline Oil Co., near the town of Locker in northern San Saba County, reported to be on an excellent structure, shows the following thickness of the various formations:

Strawn formation—Pennsylvanian	0— 394 feet.
Smithwick shale—Bend—Mississippian	394— 670 feet.
Marble Falls limestone—Bend—Mississippian	670— 760 feet.
Lower Bend shale—Mississippian	760— 805 feet.
Ellenberger limestone—Cambro—Ordovician	805—1,378 feet.

All of these wells which have penetrated the Ellenberger formation with the exception of the Brashear and Dean have been dry holes.[1] The well logs show the Ellenberger underlying the entire central Texas belt from Cooke County on the north to McCulloch and San Saba Counties on the south. A careful inspection of the logs reveals some very pertinent facts. The Smithwick shale in Eastland and Stephens counties has a thickness of 400 to 600 feet and the Marble Falls limestone likewise has a thickness of 400 to 500 feet. The well north of Myra in Cooke County shows 455 feet of Smithwick with the Marble Falls limestone entirely missing. The Matlock well in Brown County just east of Brownwood has 420 feet of Smithwick and only 180 feet of solid Marble Falls limestone which in turn rests directly upon the Ellenberger. It is important to note that this well had an eight foot gas sand in the Ellenberger formation at 2,345 which yielded several million cubic feet of gas daily and a sand showing oil at 2,353 to 2,365. This is the only test of record which has found any gas or oil in the Ellenberger limestone.

The Abney well 8 miles south of Brownwood has 360 feet of Smithwick shale and only 90 feet of "Black Lime" or Marble Falls limestone. The Dallas-Milburn well in McCulloch County has 279 feet of Smithwick shale, but no Marble Falls limestone is present. The Cawyer well has the Marble Falls limestone also completely eliminated. The Coline well, Cummings No. 1, northern San Saba County shows 276 feet of Smithwick shale and 135 feet of combined Marble Falls and Lower Bend formations. In this 135 feet there are no sands.

This data indicates conclusively that the Ellenberger lime-

[1]Production in the Brashear and Dean wells comes from the Marble Falls limestone and not from the Ellenberger.

stone[1] forms a great irregular ridge which extends in a northeasterly direction from the point of outcrop in McCulloch and San Saba Counties to the Red River, roughly paralleling the axis of the Bend arch, but at some distance to the east of the same. The Smithwick shales seem to thin somewhat to the east, but more especially towards the south in the vicinity of this ridge while the Marble Falls limestone thins to the point of eliminating all the sands of the producing horizons below the top of the lime or pinches out against the ridge completely. For this reason, southeastern Brown County, southeastern Coleman County and the greater portion of McCulloch and San Saba Counties are decidedly unfavorable areas for prospecting. Shallow production from the Strawn and Smithwick formations is about all that might be expected from such territory.

Territorial Drilling Limits of Marble Falls Limestone.—The 3,000-foot contour on the top of the Marble Falls limestone passes through the southwestern corner of Jack County, the extreme northern part of Young County, diagonally through the center of Throckmorton County in a southwesterly direction, the southeastern part of Jones County, the northwestern corner of Taylor County and the southeastern corner of Nolan County. The average elevation in this region will approximate 1,500 feet, making the total depth from the surface to the top of the Marble Falls lime along the 3,000-foot contour about 4,500 feet. Assuming 4,800-5,000 feet as the limit of practical development, all counties west and northwest of this 3,000-foot contour must be eliminated in so far as reaching the producing horizons in the Marble Falls formation is concerned. This means that Baylor, western, northern and northwestern Throckmorton, northwestern Shackelford, nearly all of Jones, the northwestern part of Taylor, and practically all of Nolan, Fisher, Stonewall, King, Haskell and Knox Counties must depend on the horizons in the Cisco formation largely for any oil. It is the Cisco sands which are yielding the prolific production from the deep wells at Electra and Burkburnett. Where the Cisco was penetrated by the deep

[1]See conclusions of William Kennedy in "Recent Knowledge of Formations Below the Bend," *Southwestern Oil Jour.*, January 4, 1919, p. 1.

well at Spur in Dickens County to the west, the formation was found to be quite bituminous in character, but composed entirely of fine, crystalline, compact limestone, indicating that the Cisco sands may change to limestone in a westward direction. Under such conditions the Cisco offers but little encouragement for prospecting since there are no sands to act as reservoirs. It becomes important, therefore, to ascertain just where this change in the Cisco begins. More information will be had on this subject when some of the tests in these western counties are completed.

Hardeman and Foard Counties must depend also largely on the development of the Cisco horizons for oil although the Bend formations might be within reach of the drill in this region owing to the proximity of the Electra, Burkburnett, Petrolia uplift. In some of the above counties covered by the Permian red beds, it is also quite likely that oil and gas may be found in red bed lenses as a result of migration.

Producing Horizons.

There are eight producing horizons in north central Texas[1] yielding oil in commercial quantity. They are:

1. **Basal Canyon (top of Strawn?) sands—Pennsylvanian.**
2. **Middle Strawn sand—Pennsylvanian.**
3. **Smithwick shale—Mississippian.**
4. **Contact Smithwick shale with Marble Falls limestone—Mississippian.**
5. **Fincher sand of the Marble Falls limestone—Mississippian**
6. **Gordon sand of the Marble Falls limestone—Mississippian.**
7. **Jones sand of the Marble Falls limestone—Mississippian.**
8. **Veale sand of the Marble Falls limestone—Mississippian.**

The only area to date producing from the basal Canyon sands is the shallow pool at Brownwood in Brown County. There is some doubt as to whether this horizon should be classed as basal Canyon. It is much more reasonable to assign this sand to the top of the Strawn series in this vicinity since the Strawn is composed essentially of sands and shales. Sandstones at the top of the Strawn beds outcropping just east of Brownwood are com-

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[1]The Electra-Burkburnett-Petrolia fields are classified as the North Texas fields and are not included within the scope of this paper.

mon. The Canyon formation is composed essentially of gray to blue, thin bedded to thick bedded, tabular to massive lenticular limestones with altering beds of blue to gray shale. Why include this sand as part of the formation? Lithologic characteristics, especially in the vicinity of Brownwood, do not justify it and the line of demarcation between the Strawn and the Canyon is largely defined by the change in lithologic character.

The middle Strawn possesses sands, generally lenticular, which have yielded small oil wells over a considerable range in central Texas. The first oil found in the region was from these sands in the vicinity of the town of Strawn in southwestern Palo Pinto County. Since the development at Ranger, several wells there have found production in this formation, some having been reported as yielding as high as 100 barrels initial production daily which is far above the average. Among such wells are the Crosby and Davis No. 1, the Holcomb No. 1 of the Cosden Oil & Gas Co., and the Warren No. 1 of the Lone Star Gas Co., the latter well being in southeastern Stephens County. The Santa Anna shallow field in Coleman County is producing from the Strawn, also gas wells several miles southwest of Bangs.

The Smithwick shale has yielded some oil and gas from lenticular sands found within the formation. The Gray wells in Coleman County, the Izod No. 1 of the Cosden Oil & Gas Co., near the Gray wells, and the first production from the Black Brothers well of the Texas Company in northern Stephens County found oil in this formation and the gas in the Allen well east of Ranger is coming from the same horizon.

Many big producing wells are obtaining their oil from the contact of the Smithwick shale and the Marble Falls limestone. This fact seems to be good evidence to support the contention that at least a disconformity exists between these two formations. The only wells yielding oil from this horizon at Ranger are the S. V. Davis with 1,200 barrels initial production, the W. L. McClesky with 1,200 barrels and the H. Brashear of McAlister et al. with 300 barrels daily production. Some of the most important wells in Stephens County, however, are getting their oil from this contact. Included in the list are the Lauderdale with 1,000 barrels, and the Sandidge with 1,000 barrels initial production.

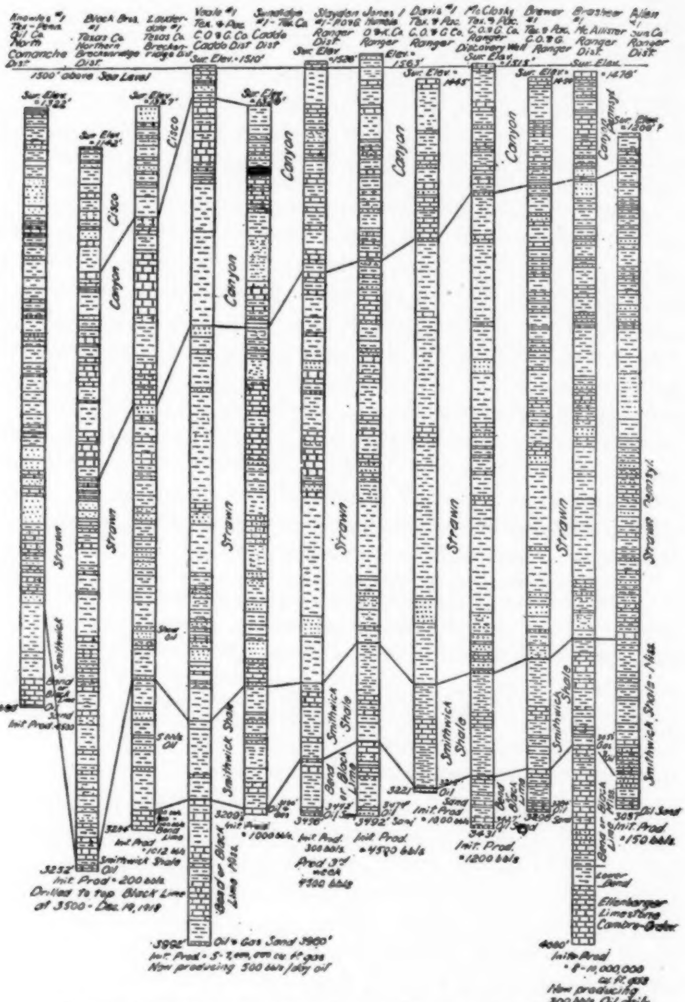

Fig. 7. Graphic Logs of Important Wells in North Central Texas Fields. The terms "Marble Falls Limestone," "Black Lime" and "Bend Lime" are used synonomously. The first has precedence but the latter two are of more common usage. The fifth well should be spelt Sandidge; the ninth McClesky. The depth of the tenth well should read 2498.

The Fincher sand, so named by the writer because the largest well in Stephens County is producing from this horizon, is about 95 feet below the top of the Marble Falls limestone. The production is really coming from a sandy limestone. This seems to be true of many wells in this county, the well logs showing 100 to 200 feet of gray limestone with sandy spots occurring within the same at various horizons. The Davis well of the Gulf Production Company which had an initial production of 1,000 barrels is getting the oil from the Fincher sand 95 feet in this gray limestone.

The Gordon sand yielded the first production at Ranger and is the horizon from which nearly all of the wells there are now producing. It is found 130 to 225 feet below the top of the Marble Falls limestone. It is a distinct sand. The production in the Duke and Knowles wells in northern Comanche County is probably coming from this same horizon. The logs of these wells show the oil to be in a gray to black lime of sandy character. This black lime is 20 feet or so in thickness and is overlain by 110 to 160 feet of gray lime which has been also classed by the writer as a part of the Marble Falls limestone since no bed of limestone of such thickness has ever been found at the base of the Smithwick shale to date. Generally 100 to 200 feet of black Smithwick shale is always found just above the Marble Falls formation.

The Jones sand, so named by the writer because it seems to be an entirely different sand from the Gordon, was first found in the Jones well at Ranger which came in with an initial production of 4,500 barrels daily. It is 325 feet below the top of the Marble Falls limestone.

The Veale sand, first found in the Veale well of the Texas & Pacific Coal, Oil & Gas Company south of Caddo in Stephens County, is 641 feet below the top of the Marble Falls limestone. Many operators have contended that this producing horizon was in the Ellenberger limestone and therefore opened up great possibilities for that formation. A close inspection of the Veale log, given elsewhere in this paper, will reveal the fallacy of this contention. The Veale sand is near the base of the Marble Falls limestone, but nevertheless a part of the same.

Thickness of Prospective Sands.—There is much speculation

as to the thickness of the producing sands. The only information to be had on this subject is from the logs of dry holes drilled through the sands. These logs show the Gordon sand to vary from six inches to 30 feet, with 18 to 20 feet a fair average and the Veale sand to be 20 feet in thickness. Whether the producing wells of large capacities will show a greater thickness of sand than given by the above figures is a question for speculation.

There is no doubt but what the sands in the Marble Falls limestone thicken and thin or pinch and often quite suddenly. For this reason, dry holes have been and will continue to be drilled on otherwise good locations from the structural standpoint. In this respect, the Ranger field is somewhat similar to the Caddo-Pine Island field of northern Louisiana where production, although intimately associated with structure, depends to a greater extent on the condition of the sand.

The number of producing horizons in the Bend series is of great economic importance when combined with the absence of salt water in some localities since it would seem to indicate that a long period of production is assured through the deepening of wells which have exhausted the sands near the top of the series. On the other hand, no two producing horizons have been encountered in any one well to date which suggests that the producing horizons are sand lenses at different depths into which the oil has migrated from the shale, the oil in any specific area seeking the nearest reservoir or lens, leaving all other such lenses in that vicinity, above or below, in a barren condition. If future development shows this to be the case, the overlapping of lenses might result in additional production through the deepening of wells in some few instances.

Character of Production.

The oil at Ranger and other central Texas fields described in this paper is high grade, light gravity 34-40 Bé crude of an olive green color. An analysis shows the following percentage of ingredients for Ranger crude:

Ranger Crude 38.5°. Baume at 60° F.

Gasoline	22.0 per cent., 59.9 gravity.
Naphthas	3.8 per cent., 52.3 gravity.
Kerosene	21.8 per cent., 43.9 gravity.
Residue (lubricating and fuel oil not separated)	

The combination of quality and quantity of production obtained from the wells at Ranger, Breckenridge, the Duke vicinity, etc., has attracted the attention of operators throughout the country. The writer has tried to obtain voluminous statistics showing the date wells were drilled in, the initial production, and the present production in order to give some idea of how the production of the big wells was holding up. This information was only partly available at the time this paper was completed. Some gauge as to the exceptional manner in which the wells of large capacity are maintaining their production may be gained by reference to the record of the McClesky discovery well and its offset, the Davenport. These wells were drilled in with an initial production of approximately 1,200 barrels daily each and one year from date, each well was making better than 500 barrels daily. If other wells show similar tendencies, it is conservative to state that Ranger is likely to establish a new record for high average production and longevity per well. A short table showing the date, initial and present production of some of the most important wells in the Ranger and Stephens County fields is given on following page.[1]

Summary.

1. The development in north central Texas following the Ranger discovery has resulted in the opening of six new additional fields of great promise, namely, Breckenridge, Caddo, Veale, Black Brothers, Allen and Duke.

2. The discovery of these new fields has inaugurated the greatest wildcat campaign in the history of Texas, extending from the Trinity River on the east into the Trans-Pecos country.

3. Geological investigation has demonstrated that slight surface structure of small areal extent in the Pennsylvanian in the form of wrinkles, noses, terraces, etc., is generally indicative of structure in the Bend Series of Mississippian age.

4. The sub-surface structure in the Bend formation is much more pronounced, better defined, and of much greater extent,

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[1]Additional production statistics, for all the wells of the Ranger pool, obtained just as this paper went to press, may be found in *The Oil & Gas Journal,* Feb. 28, 1919, p. 42.

Well.	Owner	Date Drilled in	Initial Production	Estimated Production End of fourth Mo
J. H. McClesky, No. 1	Texas & Pacific Coal Co.	10-25-17	1,200 bbls	850 bbls.
S. Davenport, No. 1	Texas & Pacific Coal Co.	About 12-22-17	1,200 bbls	850 bbls.
F. Brewer, No. 1	Texas & Pacific Coal Co.	6-10-18	2,191 bbls.	1,250 bbls.
F. Brewer, No. 2	Texas & Pacific Coal Co.	8-14-18	3,100 bbls.	?
Merriman, No. 11	Texas & Pacific Coal Co.	8-14-18	1,500 bbls.	?
Merriman, No. 1	Wagner, et al	?	3,800 bbls.	?
I. Slayden, No. 1	Prairie Oil & Gas Co.	7-4-18	300 first week, then 4,500 daily	1,600 bbls.
Jones, No. 1	Humble Oil & Refining	7-8-18	4,500 bbls.	650 bbls.
Jones No. 2	Humble Oil & Refining	About 9-28-18	1,800 bbls.	1,400 bbls.
Gholson, No. 1	Bartles, et al	?	900 bbls.	550 bbls.
Davis, S. V. No. 1	Texas & Pacific Coal Co.	7-29-18	1,000 bbls.	750 bbls.
Duncan, No. 1	Texas & Pacific Coal Co.	6-3-18	800 bbls.	350 bbls.
Lauderdale, No. 1	Texas Co.	About 3-25-18	1,200 bbls.	500 bbls.
Sandidge, No. 1	Texas Co.	April, 1918	1,000 bbls.	950 bbls.
Fincher, No. 2	Gulf Production Co.	9-18-18	At first 650 bbls. later 1,800	1,300 bbls.
Davis No. 1	Gulf Production Co.	9-18-18	1,000 bbls.	600 bbls.

Note.—Last four wells are in Stephens County, rest in Ranger field.

areally, than the surface structure in the Pennsylvanian rocks.

5. All the new fields developed to date show some manifestation of surface structure. At least 70 per cent. of such surface structures in the Pennsylvanian formations which have been drilled to date have yielded oil or gas in commercial quantity.

6. Blind structure, or structure with commercial possibilities in the Bend that has no surface manifestations, occurs in a few instances.

7. The chief value of surface structure results from the fact that it serves as a reliable guide for initial developments. Wells favorably located with respect to the surface structure will generally be productive, but after the drilling of the first few wells, intelligent development must be directed from a close study of the sub-surface structure through the medium of well logs.

8. Favorable structural conditions for commercial accumula-

tion of oil occur where cross folding has been superimposed upon extensive flexures resulting from the uplift which produced the Bend arch. The trend of the axis of the flexures is generally slightly northeast-southwest while the direction of the axes of the cross folds is nearly at right angles to the axes of the flexures.

9. A study of tectonic relationships shows the various fields to be situated along certain definite axes corresponding to the axis of the flexures resulting from the secondary folding associated with the Bend uplift. These axes are rougly parallel and are three in number, namely, the Eastland-Breckenridge-Black axis, the Caddo-Veale-Ranger axis, and the Strawn-Allen-Duke axis.

Fig. A.—Ranger, Texas, during the days of early development, July, 1918.

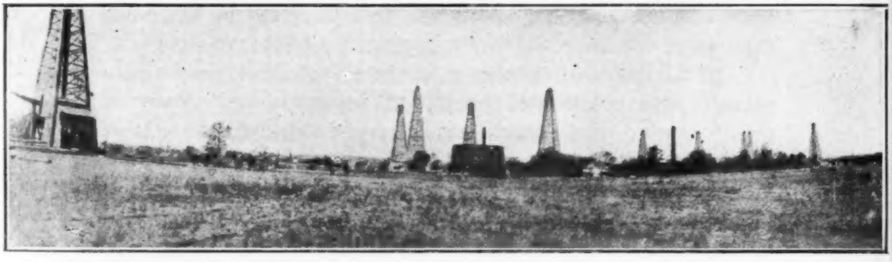


Fig. B.—Brewer Hill, one of the richest spots in the Ranger Field. All the wells on this hill have averaged better than 1,800 bbls. daily initial production.

10. There are eight producing oil horizons in the central Texas

formations. Six of these horizons belong to the Bend series and five of the latter six are in the "Black Lime" or Marble Falls limestone which is the source of the most prolific production.

11. The west and northwest side of the structures generally yield the largest and best wells. Production extends a considerably greater distance down the west and northwest side than the reverse or southeast side.

12. Although production is intimately associated with structure in the Bend, the condition of the sands is of equal importance. Where the sands pinch or are of a non-porous character, dry holes result even though favorably situated from a structural standpoint.

13. The Ellenberger limestone has formed a great ridge against which the prolific Marble Falls formation pinches out partially or completely in an easterly and southerly direction. These conditions have resulted in the practical elimination of several counties from the probable producing class since the Ellenberger has no value as an oil horizon.

14. The general absence of salt water and the unusual staying qualities of the wells in the Ranger field indicate a long life for this region with a high average production per well.

15. The developments of the next few months will undoubtedly result in the discovery of several new fields. The best territory for investigation preparatory to prospecting will be found by projecting the parallel axes through the various fields already under development and noting the area traversed by extending these axes.

16. A number of counties west of the Permian-Pennsylvanian contact have possibilities worthy of investigation. Many of these counties must depend largely on the Burkburnet sands of the Cisco formation for production, however, as the Marble Falls limestone, if present, will in general lie beyond a practical drilling depth. The presence of the Burkburnet sands in this western area is yet to be determined by the drill.

17. Cretaceous formations east of the outcrops of the Pennsylvanian completely obscure the structural features of the latter in many instances. Where structure in the Cretaceous is observed in counties bordering the eastern Pennsylvanian-Cretaceous contact, such structures should be tested.

REPRESENTATIVE LOGS OF VARIOUS CENTRAL TEXAS FIELDS.[1]

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, J. Phillips. Well Owner, Prairie O. & G. Co. Sheet No. 1.

Formation	From	To	Amt.	Formation	From	To	Amt.
Mud	0	10	10	Blue slate	1815	1900	85
Quick sand	10	25	15	Gray lime	1900	1930	30
Gravel	25	35	10	Blue slate	1930	2000	70
Lime	35	60	25	Lime and sand	2000	2060	60
Quick sand	60	65	5	Blue slate	2060	2075	15
Slate	65	80	15	Lime	2075	2100	25
White lime	80	85	5	Blue slate	2100	2290	190
Blue slate	85	120	35	Blue lime	2290	2305	15
White lime	120	130	10	Blue slate	2305	2350	45
Blue slate	130	145	15	Sand	2350	2375	25
Gray lime	145	155	10	Blue slate	2375	2390	15
Blue slate	155	220	65	Sand	2390	2440	50
Gray lime	220	230	10	Gray lime	2440	2455	15
Blue slate	230	330	100	Blue slate	2455	2475	20
White lime	330	350	20	Sand	2475	2500	25
Blue slate	350	390	40	Slate	2500	2515	15
Lime	390	400	10	Lime	2515	2525	10
Blue slate	400	430	30	Sand	2525	2620	95
Lime	430	445	15	Slate	2620	2625	5
Blue slate	445	480	35	Lime and sand	2625	2660	35
Sand	480	575	95	Blue slate	2660	2700	40
Blue slate	575	600	25	Blue lime	2700	2725	25
Sand	600	660	60	Dark slate	2725	2860	135
Slate	660	765	105	Dark lime	2860	2895	35
Lime	765	800	35	Black slate	2895	2930	35
Blue slate	800	980	180	Lime	2930	2965	35
Gray lime	980	1000	20	Black slate	2965	3045	80
Blue slate	1000	1155	155	Lime	3045	3060	15
Sand—water	1155	1220	65	Black slate	3060	3200	140
Slate	1220	1235	15	Black lime	3200	3260	60
Slate	1235	1260	25	Gray lime	3260	3300	40
Slate	1260	1270	10	Black lime	3300	3380	80
Gray lime	1270	1275	5	Brown lime	3380	3390	10
Blue slate	1275	1445	170	Sand and lime	3390	3410	20
Lime	1445	1465	20	Black slate	3410	3445	35
Slate	1465	1480	15	White lime	3445	3470	25
Sand	1480	1510	30	Black lime	3470	3500	30
Blue slate	1510	1535	25	Gray lime	3500	3520	20
Sand	1535	1560	25	Black lime	3520	3560	40
Slate	1560	1575	15	Gray lime	3560	3650	90
Gray lime	1575	1585	5	Slate	3650	3660	10
Blue slate	1580	1600	20	Lime	3660	3760	100
Lime	1600	1610	10	Slate	3760	3765	5
Slate	1610	1625	15	Black lime	3765	3800	35
Lime and sand	1625	1675	50	Slate	3800	3850	50
Slate	1675	1680	5	Blue lime	3850	3875	25
Lime	1680	1695	15	Blue lime	3875	3895	20
Blue slate	1695	1705	10	Gray lime	3895	3910	15
Gray lime	1705	1720	15	Blue lime	3910	3960	50
Slate	1720	1725	5	White lime	3960	3990	30
Gray lime	1725	1760	35	Blue lime	3990	4000	10
Slate	1760	1790	30	White lime	4000	4005	5
Lime	1790	1815	25	Blue lime	4005	4010	5

Total Depth—4010.
Initial Production—Dry—Show of oil at 3390.

CORRELATION SUMMARY.

0- 445—Canyon—Pennsylvanian.
445-2725—Strawn—Pennsylvanian.
2725-3200—Smithwick Shale—Upper Bend—Mississippian.
-3200—Top of "Black or Bend Lime" formation—Middle Bend—Mississippian.
3200-3760—"Black or Bend Lime"—Middle Bend—Mississippian.
3760-3850—Lower Bend—Mississippian.
3850-bottom—Ellenberger Limestone—Cambro-Ordovician.

[1]The following tables are copied from the regular form of well logs, with certain of the unused columns for the sake of space.

State, Texas. County, Stephens. District, Caddo. Well No. 1. Farm, Sandidge. Well Owner, Texas Co. Sheet No. 1.

Formation	From	To	Amt.	Formation.	From	To	Amt.
Yellow sand	0	4	4	Sand and water	1592	1617	25
Shale	4	11	7	Blue shale	1617	1648	31
Blue shale	11	90	79	Dark shale	1648	1690	42
Black shale	90	130	40	Sandy shale	1690	1745	55
Lime shell	130	150	20	Blue shale	1745	1850	105
Red shale	150	152	2	Gritty lime	1850	1978	128
Lime	152	160	8	Blue shale	1978	1990	12
Blue shale	160	190	30	Sandy shale	1990	2100	110
Pink lime	190	210	20	Sand and water	2100	2135	35
Blue shale	210	220	10	Shale	2135	2150	15
Sand	220	250	30	Broken sand	2150	2158	8
Blue shale	250	280	30	Blue shale	2158	2210	52
Coal	280	320	40	Black shale	2210	2240	30
Blue shale	320	330	10	Sand	2240	2285	45
Lime	330	370	40	Blue shale	2285	2335	50
Blue shale	370	385	15	Sand—little oil and gas	2335	2345	10
White lime	385	450	65	Blue shale	2345	2390	45
Blue shale	450	470	20	Sand	2390	2393	3
Pink lime	470	485	15	Shale	2393	2410	17
Blue shale	485	595	110	Gas sand	2410	2496	86
Blue sandy shale	595	795	200	Water sand	2496	2510	14
Blue shale	795	810	15	Sand	2510	2516	6
Lime	810	860	50	Blue shale	2516	2530	14
Blue shale	860	870	10	Sand	2530	2541	11
Lime	870	880	10	Blue shale	2541	2550	9
Blue shale	880	910	30	White lime	2550	2600	50
Pink lime	910	930	20	Black shale	2600	2606	6
Blue shale	930	945	15	Sand	2606	2620	14
Gray lime	945	950	5	Blue shale	2620	2626	6
Blue shale	950	970	20	Black shale	2626	2680	54
Gray lime	970	980	10	Brown shale	2680	2740	60
Blue shale	980	995	15	Dry sand	2740	2750	10
Gray lime	995	1005	10	Black shale	2750	2774	24
Black sandy shale	1005	1055	50	Dry sand	2774	2790	16
Black shale	1055	1080	25	Black shale	2790	2840	50
Black sandy shale	1080	1105	25	Dry sand	2840	2855	15
Sand	1105	1120	15	White slate	2855	2870	15
Dark sandy shale	1120	1145	25	Dry sand	2870	2880	10
Black sandy shale	1145	1240	95	Blue shale	2880	2961	81
Blue shale	1240	1260	20	Brown shale	2961	3000	39
Gray lime	1260	1380	120	Black shale	3000	3060	60
Blue shale	1380	1385	5	Sandy lime	3060	3085	25
Gray lime	1385	1398	13	Black lime	3085	3114	29
Dark shale	1398	1408	10	Blue shale	3114	3119	5
Blue shale	1408	1452	44	Blue shale	3119	3180	61
Gray lime	1452	1582	130	Black lime—oil and gas	3180	3208	28
Blue shale	1582	1592	10				

Total depth—3209½ feet.
Depth of producing horizon below top of "Black Lime"—00 feet.
Initial production—1000 bbls.

CORRELATION SUMMARY.

0-1005—Canyon formation—Pennsylvanian.

1005-2620—Strawn formation—Pennsylvanian.

2620-3180—Smithwick Shale — Upper Bend—Mississippian.

-3180—Top of "Black or Bend Lime"—Middle Bend—Mississippian.

State, Texas. County, Stephens. District, Breckenridge. Well No. 1. Farm, J. A. Lauderdale. Well Owner, Texas Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Derrick floor to ground	0	3	3	Lime shell	174	182	8
Sand rock	3	76	73	Blue shale	182	234	52
Blue shale	76	85	9	Limestone	234	245	11
Lime shell	85	89	4	Blue shale	245	270	25
Red rock	89	100	11	Limestone	270	274	4
Blue shale	100	132	32	Sand—fresh water	274	283	9
Sand—little water	132	146	14	Blue shale	283	286	3
Blue shale	146	174	28	Dry sand	286	300	14

State, Texas. County, Stephens. District, Breckenridge. Well No. 1. Farm, J. A. Lauderdale. Well Owner, Texas Co. Sheet No. 2.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Limestone	300	307	7	Limestone	1891	1896	5
Blue shale	307	312	5	Blue shale	1896	1960	64
Light shale	312	348	36	Limestone	1960	1971	11
Water sand	348	359	11	Blue shale	1971	2005	34
Blue shale	359	362	3	Sandy shale	2005	2010	5
Light shale	362	367	5	Dry sand	2010	2020	10
Sandy shale	367	385	18	Sand—gas	2020	2026	6
Blue shale	385	400	15	Water sand	2026	2050	24
Light shale	400	415	15	Blue shale	2050	2054	4
Dark shale	415	506	91	Limestone	2054	2058	4
Black lime	506	513	7	Dry sand	2058	2068	10
Blue shale	513	519	6	Water sand	2068	2098	30
White limestone	519	532	13	Blue shale	2098	2128	30
Blue shale	532	539	7	Sandy shale	2128	2146	18
White limestone	539	582	43	Light blue shale	2146	2153	7
Blue shale	582	655	73	Limestone	2153	2156	3
Black shale	655	670	15	Blue shale	2156	2180	24
White limestone	670	946	276	Light blue shale	2180	2210	30
Broken lime	946	980	34	Blue shale	2210	2250	40
Dark shale	980	1135	155	Limestone	2250	2255	5
Blue shale	1135	1165	30	Light blue shale	2255	2270	15
Limestone	1165	1217	52	Blue shale	2270	2370	100
Shale—light	1217	1220	3	Shell	2370	2372	2
Limestone	1220	1236	16	Sand—showing oil	2372	2386	14
Gritty lime	1236	1240	4	Water sand	2386	2429	43
Gray shale	1240	1249	9	Black slate	2429	2435	6
White limestone	1249	1268	19	Sandy shale	2435	2439	4
Blue shale	1268	1278	10	Dry sand	2439	2443	4
White limestone	1278	1330	52	Limestone	2443	2445	2
Blue shale	1330	1346	16	Limestone	2445	2460	15
Limestone	1346	1363	17	Blue shale	2460	2583	123
Water sand	1363	1413	50	Dry sand	2583	2600	17
Blue shale	1413	1416	3	Blue sandy shale	2600	2630	30
White limestone	1416	1421	5	Blue shale	2630	2730	100
Blue shale	1421	1424	3	Limestone	2730	2734	4
Sandy lime	1424	1433	9	Dry sand	2734	2738	4
Blue shale	1433	1436	3	Gas sand	2738	2740	2
Sandy shale	1436	1445	9	Dry sand	2740	2785	45
Blue shale	1445	1508	63	Blue shale	2785	2855	70
Limestone	1508	1529	21	Sand—5 bbls. of oil	2855	2861	6
Gray shale	1529	1580	51	Sand	2861	2869	8
Limestone	1580	1635	55	Blue shale	2869	2892	23
Red shale	1635	1644	9	Dry sand	2892	2920	28
Brown shale	1644	1657	13	Blue shale	2920	2995	75
Gray shale	1657	1671	14	Dry sand	2995	3012	17
Blue shale	1671	1685	14	Blue shale	3012	3188	176
Limestone	1685	1697	12	Gray lime	3188	3209	21
Blue shale	1697	1772	75				
Gray shale	1772	1825	53	Gray lime—est. 160 bbls. oil daily	3209	3215	6
Red rock	1825	1836	11				
Water sand	1836	1838	2	Gray lime—est. 400 bbls. oil daily	3215	3219	4
Sand	1838	1844	6	Lime—dry	3219	3228	9
Sandy shale	1844	1850	6				
Dry sand	1850	1886	36	Lime—gray—hard—1015 bbls. oil daily est.	3228	3234	6
Blue shale	1886	1891	5	Black lime	3234	3284	50

Total Depth—3284 feet.
Depth of Oil Sand or Producing Horizon below "Top or Black or Bend Lime"—00 feet.
Initial production reported—800-1000 bbls. oil daily.

CORRELATION SUMMARY.

0- 519—Cisco formation—Pennsylvanian.
519-1363—Canyon formation—Pennsylvanian.
1363-2600—Strawn formation—Pennsylvanian.
2600-3188—Smithwick Shale—Upper Bend—Mississippian.
-3188—Top of "Black or Bend Lime"—Middle Bend—Mississippian. Hole finished in the Black or Bend Lime formation.

State, Texas. County, Stephens. District, Breckenridge. Well No. 1. Farm, Black Bros. Well Owner, Texas Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Surface soil	0	10	10	Sand	1710	1720	10
Yellow mud	10	30	20	Slate	1720	1745	25
Blue shale	30	60	30	Slate	1745	1770	25
Lime	60	70	10	Lime	1770	1795	25
Sand	70	92	22	Blue slate	1795	1865	70
Blue shale	92	204	112	Lime	1865	1870	5
Lime	204	230	26	Blue slate	1870	1875	5
Blue shale	230	285	55	Soapstone	1875	1885	10
Lime	285	292	7	Blue slate	1885	1896	11
Blue shale	292	302	10	Lime	1896	1911	15
Lime	302	306	4	Blue slate	1911	1990	79
Black shale	306	313	7	Lime	1990	1995	5
Lime	313	319	6	Sand	1995	2000	5
Blue shale	319	348	29	Blue shale	2000	2195	195
Lime	348	355	7	Lime	2195	2220	25
Blue shale	355	362	7	Slate	2220	2255	35
Water sand	362	410	48	Lime	2255	2290	35
Lime	410	438	28	Slate	2290	2320	30
Blue shale	438	540	102	Water sand	2320	2330	10
Black shale	540	552	12	Sand	2330	2340	10
Lime	552	621	69	Lime	2340	2355	15
Sand	621	627	6	Blue slate	2355	2385	30
Lime	627	640	13	Lime	2385	2395	10
Blue shale	640	740	100	Blue slate	2395	2415	20
Lime	740	746	6	Water sand	2415	2420	5
Water sand	746	766	20	Lime	2420	2440	20
Black shale	766	770	4	Blue slate	2440	2523	83
Blue shale	770	798	28	Lime	2523	2528	5
Sandy lime	798	811	13	Sandy lime	2528	2540	12
Blue shale	811	844	33	Hard lime	2540	2555	15
Lime	844	875	31	Sand	2555	2570	15
Blue shale	875	886	11	Blue shale	2570	2580	10
Lime	886	891	5	Sand	2580	2595	15
Blue shale	891	940	49	Brown shale	2595	2705	110
Lime	940	961	21	Slate	2705	2710	5
Blue shale	961	973	12	Sandy lime	2710	2725	15
Blue lime	973	994	21	Blue shale	2725	2765	40
White lime	994	1070	76	Lime	2765	2770	5
Blue shale	1070	1135	65	Brown shale	2770	2795	25
Lime	1135	1140	5	Lime	2795	2815	20
Blue shale	1140	1273	133	Blue shale	2815	2850	35
Lime	1273	1320	47	Slate	2850	2870	20
White shale	1320	1328	8	Lime	2870	2880	10
White lime	1328	1390	62	Blue slate	2880	2900	20
White slate	1390	1395	5	Lime	2900	2910	10
Blue lime	1395	1430	35	Slate	2910	2955	45
Blue shale	1430	1475	45	Lime	2955	2960	5
Lime	1475	1480	5	Blue shale	2960	2975	15
Sharp sand	1480	1490	10	Lime	2795	2980	5
White shale	1490	1505	15	Shale	2980	3005	25
Water sand	1505	1520	15	Sand	3005	3015	10
Blue slate	1520	1528	8	Slate	3015	3025	10
Sharp sand	1528	1531	3	Lime	3025	3030	5
Blue slate	1531	1535	4	Shale	3030	3045	15
Lime	1535	1540	5	Lime	3045	3050	5
Lime	1540	1545	5	Blue shale	3050	3095	45
Blue slate	1545	1560	15	Sandy lime—water	3095	3120	25
Lime	1560	1570	10	Blue shale	3120	3135	15
Blue shale	1570	1580	10	White shale	3135	3145	10
Water sand	1580	1625	45	White lime	3145	3175	30
Sand	1625	1660	35	Shale	3175	3184	9
Blue shale	1660	1670	10	White lime	3184	3200	16
Lime	1670	1685	15	Black shale	3200	3225	25
Sand	1685	1700	15	Black shale	3225	4240	15
Lime	1700	1710	10	Gray lime—oil	3240	3252	12

Total depth—3252 feet.
Oil sand—40 feet below top of Smithwick shale.
Initial production—About 200 bbls. daily.
Drilled deeper to approximately 3500 feet—Dec. 19, 1918.

CORRELATION SUMMARY.

0- 552—Cisco formation—Pennsylvanian.
552-1480—Canyon formation—Pennsylvanian.
1480-3200—Strawn formation — Pennsylvanian.
3200-bottom—Smithwick Shale—Upper Bend—Mississippian. Top of "Black or Bend Lime" reported at 3500 feet.

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, Allen. Well Owner, Sun Company. Sheet No. 1.

Formation.	From	To	Amt.
Clay	0	10	10
Shell	10	12	2
Blue shale	12	70	58
Red rock	70	75	5
Lime	75	85	10
Blue shale	85	90	5
Lime	90	95	5
Blue shale	95	120	25
Lime	120	130	10
White shale	130	160	30
Blue shale	160	220	60
White shale	220	240	20
Blue shale	240	290	50
White shale	290	300	10
Blue shale	300	322	22
Lime	322	325	3
Blue shale	325	345	20
White shale	345	357	12
Blue shale	357	380	23
White shale	380	390	10
Blue shale	390	416	26
White shale	416	430	14
Blue shale	430	472	42
Sand—gas	472	498	26
Sandy shale	498	520	22
Blue shale	520	600	80
Dark shale	600	610	10
Blue shale	610	638	28
Lime	638	644	6
Blue shale	644	665	21
Sandy shale—gas	665	680	15
Blue shale	680	704	24
Lime	704	716	12
Blue shale	716	770	54
Water sand	770	798	28
Gumbo	798	800	2
Blue shale	800	822	22
Water sand	822	845	23
Blue shale	845	858	13
Lime	858	864	6
Blue shale	864	1007	143
Blue shale	1007	1080	73
Sandy shale	1080	1285	205
White slate	1285	1370	85
Lime shell	1370	1375	5
White slate	1375	1412	37
Sandy shale	1412	1427	15
Blue shale	1427	1457	30
Lime shell	1457	1460	3
Sandy shale	1460	1480	20
Sand—gas	1480	1510	30
Dark shale	1510	1520	10
Sand	1520	1535	15
Sand and shale	1535	1542	7
Shell	1542	1550	8
Slate	1550	1560	10
Sand	1560	1576	16
Shale	1576	1600	24
Lime	1600	1605	5
Sandy shale	1605	1616	11
Lime	1616	1645	29
Blue shale	1645	1661	16
Lime	1661	1664	3
Blue shale	1664	1700	36
Sand	1700	1732	32
Black shale	1732	1775	43
Slate	1775	1800	25
Lime	1800	1820	20
Blue shale	1820	1875	55
Blue slate	1875	1885	10
Blue shale	1885	1915	30
Black sand	1915	1930	15
Dark slate	1930	1975	45
Black lime	1975	1980	5
Black shale	1980	2015	35
Sand shells	2015	2035	20
Sandy shale	2035	2050	15
Black shale	2050	2075	25
Sandy shale	2075	2115	40
Sandy lime	2115	2150	35
Blue shale	2150	2180	30
Lime	2180	2185	5
Blue shale	2185	2190	5
White lime	2190	2200	10
Blue slate	2200	2210	10
Sandy shale	2210	2245	35
Lime	2245	2280	35
Black shale	2280	2305	25
Black slate	2305	2325	20
Black shale and slate	2325	2425	100
Pink shale	2425	2455	30
Black shale	2455	2460	5
Sandy shale	2460	2465	5
Sandy shale	2465	2500	35
Black shale	2500	2540	40
Sand—little gas	2540	2550	10
Black shale	2550	2660	110
Black slate or shale	2660	2695	35
Black shale	2695	2737	42
Black lime	2737	2757	20
Sand—gas	2757	2763	6
Black shale	2763	2771	8
Sandy lime	2771	2791	20
Sandy shale	2791	2800	9
Sandy lime	2800	2806	6
Sandy lime	2806	2812	6
Sand—good oil show	2812	2820	8
Sandy lime	2820	2826	6
Blue slate	2826	2830	4
Sandy lime	2830	2836	6
Sandy lime—gray	2836	2845	9
Gas sand—6,000,000 cu. ft.	2845	2854	9
Gas sand	2854	2858	4
Sandy lime	2858	2865	7
Black slate	2865	2873	8
Sand	2873	2875	2
Cap rock—8 million gas—show oil	2875	2879	4
Sandy lime	2879	2890	11
Sandy lime	2890	2894	4
Black slate	2894	2896	2
Gray sandy lime	2896	2921	25
Black sandy lime	2921	2941	20
Black sandy lime	2941	2948	7
Black slate	2948	2960	12
Black shale	2960	2990	30
Black sandy lime	2990	3000	10
Black shale	3000	3014	14
Gray slate	3014	3022	8
Black shale and brown lime	3022	3032	10
Brown sandy lime—oil	3032	3037	5

Total Depth—3037 feet.

Depth of Oil Sand below top of "Black or Bend Lime"—141.

Initial Production—150 bbls. oil daily with sand barely pentrated and tools in hole.

CORRELATION SUMMARY.

0- 160—Canyon formation — Pennsylvanian.

160-2280—Strawn formation — Pennsylvanian.

2280-2896—Smithwick Shale — Upper Bend—Mississippian.

-2896—Top of "Black or Bend Lime."

State, Texas. County, Stephens. District, Caddo. Well No. 1. Farm, Veale. Well Owner, T. & P. Coal, O. & G. Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Soil	0	4	4	Blue shale	2425	2475	50
Lime	4	60	56	Gray lime	2475	2482	7
Blue shale	60	68	8	Blue shale	2482	2500	18
Gray lime	68	75	7	Lime	2500	2503	3
Water sand	75	85	10	Sand—dry	2503	2510	7
Blue shale	85	93	8	Gray lime	2510	2518	8
Water sand	93	128	35	Blue shale	2518	2527	9
Blue shale	128	157	29	Sand—dry	2527	2534	7
Gray lime	157	164	7	Shale and lime	2534	2590	56
Blue shale	164	174	10	Blue shale	2590	2635	45
Gray lime	174	249	75	Lime	2635	2642	7
Blue shale	249	280	31	Sand—dry	2642	2665	23
Lime	280	310	30	Blue shale	2665	2675	10
Blue shale	310	355	45	Gray lime	2675	2685	10
Lime	355	390	35	Blue shale	2685	2708	23
Blue shale	390	396	6	Lime and sand	2708	2741	33
Gray lime	396	455	59	Water sand	2741	2756	15
Blue shale	455	467	12	Blue shale	2756	2776	20
Gray lime	467	487	20	Dry sand	2776	2845	69
Water sand	487	502	15	Blue shale	2845	2857	12
Blue shale	502	522	20	Lime, sand and shale	2857	2960	103
Dry sand	522	535	13	Blue shale	2960	3005	45
Gray lime	535	550	15	Black shale	3005	3205	200
Blue shale	550	790	240	Black lime	3205	3209	4
Pink shale	790	795	5	Black shale	3209	3215	6
Blue shale	795	1248	453	Black lime	3215	3218	3
Dry sand	1248	1298	50	Black shale	3218	3250	32
Blue shale	1298	1360	62	Black lime	3250	3254	4
Pink shale	1360	1367	7	Black shale	3254	3319	65
Gray lime	1367	1372	5	Black lime	3319	3349	30
Pink shale	1372	1384	12	Black shale	3349	3382	33
Blue shale	1384	1540	156	Black lime	3382	3398	16
Gray lime	1540	1546	6	Black shale	3398	3408	10
Sand—dry	1546	1553	7	Black lime	3408	3416	8
Blue shale	1553	1765	212	Black shale	3416	3433	17
Gray lime	1765	1771	6	Blue shale	3433	3538	105
Blue shale	1771	2082	311	White lime	3538	3578	40
Gray lime	2082	2120	38	Black lime and shale	3578	3717	139
Broken sand—gas	2120	2128	8	Black lime	3717	3877	160
Shale	2128	2133	5	Black shale	3877	3960	83
Sand—dry	2133	2180	47	Gas sand	3960	3980	20
Shale—blue	2180	2415	235	Lime and shale	3980	3992	12
Gray lime	2415	2425	10				

Total Depth—3992 feet.
Depth of Oil Sand below top of "Black or Bend Lime"—641.
Initial Production—5-7,000,000 cu. ft. gas. After several months started to flow oil. Now producing 500 bbls. oil daily.

CORRELATION SUMMARY.

0- 157—Cisco formation — Pennsylvanian.
157-1248—Canyon formation—Pennsylvanian.
1248-2960—Strawn formation—Pennsylvanian.
2960-3319—Smithwick Shale — Upper Bend—Mississippian.
-3319—Top of Bend or Black Lime.

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, H. Brashear. Well Owner, McAlister et al. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Soil	0	13	13	Lime	135	139	4
Lime	13	25	12	Blue shale	139	177	38
Rock	25	39	14	Lime	177	181	4
Blue shale	39	43	4	Blue shale	181	190	9
Lime	43	47	4	Dry sand	190	200	10
Blue shale	47	67	20	Blue shale	200	202	2
Lime	67	74	7	Lime	202	292	90
Blue shale	74	96	22	Blue shale	292	300	8
Lime	96	100	4	Lime	300	306	6
Blue shale	100	106	6	Blue shale	306	322	16
Lime and sand	106	127	21	Lime	322	343	21
Blue shale	127	135	8	Blue shale	343	348	5

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, H. Brashear. Well Owner, McAlister et al. Sheet No. 2.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Lime	348	359	11	White shale	1665	1690	25
Blue shale	359	390	31	Lime	1690	1692	2
Sandy lime—water	390	395	5	Blue shale	1692	1800	108
Shale	395	425	30	Black shale	1800	1820	20
Sand	425	437	12	White shale	1820	1927	107
Shale	437	445	8	Lime	1927	1930	3
Sand—shelly	445	485	40	Blue shale	1930	2290	360
Shale	485	492	7	Lime	2290	2300	10
Lime	492	495	3	Shale	2300	2302	2
Sand	495	584	89	Dry sand	2302	2307	5
Blue shale	584	590	6	Shale	2307	2340	33
Red mud	590	598	8	Dry sand	2340	2360	20
Shale	598	612	14	Shale	2360	2375	15
Lime	612	614	2	Sand	2375	2381	6
Blue shale	614	640	26	Shale	2381	2432	51
White shale	640	680	40	Lime	2432	2435	3
Blue shale	680	708	28	Shale	2435	2445	10
Lime	708	712	4	Broken dry sand	2445	2515	70
Blue shale	712	757	45	Blue shale	2515	2555	40
Sand	757	760	3	Black shale	2555	2620	65
Blue shale	760	775	15	Lime	2620	2625	5
Water sand	775	793	18	Blue lime	2625	2710	85
Blue shale	793	846	53	Black lime	2710	2716	6
Lime	846	850	4	Black shale	2716	2740	24
Sand	850	857	7	Blue lime	2740	2783	43
Shale	857	870	13	Black shale	2783	2870	87
Dry sand	870	876	6	Black lime	2870	2875	5
Blue shale	876	971	95	Shale and shells	2875	3035	160
Lime	971	979	8	Black lime—gas	3035	3075	40
Blue shale	979	1005	26	Black shale	3075	3078	3
Blue lime	1005	1020	15	Black lime—little gas	3078	3084	6
Shale	1020	1095	75	Black shale	3084	3087	3
Lime and sand	1095	1100	5	Black lime	3087	3110	23
White shale	1100	1106	6	Black shale	3110	3146	36
Sand	1106	1114	8	Lime	3146	3179	33
Shale	1114	1120	6	Gray lime	3179	3199	20
Sand	1120	1132	12	Dark gray lime	3199	3205	6
Shale	1132	1141	9	Black lime and shelly shale	3205	3249	44
Lime	1141	1146	5	Gray lime	3249	3279	30
Blue shale	1146	1390	244	Black lime and shale	3279	3285	6
Lime	1390	1393	3	Gray lime and shale	3285	3297	12
Blue shale	1393	1413	20	Gray lime	3297	3312	15
Lime and gas sand	1413	1418	5	Lime—show oil	3312	3321	9
Water sand	1418	1440	22	Lime and shale	3321	3328	7
White shale	1440	1445	5	Gray lime	3328	3334	6
Lime	1445	1459	14	Lime	3334	3357	23
Shale	1459	1465	6	Black shale	3357	3370	13
Blue shale	1465	1469	4	Gray lime	3370	3378	8
Lime	1469	1487	18	Shells and shale	3378	3395	17
Dry sand	1487	1495	8	Gray lime	3395	3408	13
Shale	1495	1512	17	Blue shale	3408	3409	1
Lime	1512	1517	5	White lime and sand	3409	3425	16
White shale	1517	1557	40	Blue shale	3425	3426	1
Lime	1557	1570	13	White sandy lime	3426	3478	52
Blue shale	1570	1576	6	Black lime	3478	3517	39
Sandy lime	1576	1583	7	Black shale	3517	3523	6
Shale	1583	1606	23	Broken shale and shell	3523	3570	47
Water sand	1606	1650	44	? ?	3570	3665	95
Shale	1650	1651	1	White lime	3665	4000	335
Lime	1651	1665	14				

Total depth—4000 feet.

Depth of oil sand below top of Black Lime—00 ft.

Initial Production—6,000,000 cu. ft. of gas. After several shots and three or four months of gas flow, well started making oil. Now said to be making 300 bbls. daily.

CORRELATION SUMMARY.

0- 495—Canyon formation—Pennsylvanian.

495-2555—Strawn formation—Pennsylvanian.

2555-3035—Smithwick shale — Upper Bend—Mississippian.

-3035—Top of "Black or Marble Falls Lime"—Mississippian.

3035-3523—"Black Lime" or Bend Lime—Middle Bend formation—Mississippian.

3523-3665—Lower Bend formation—Mississippian.

3665-to bottom—Ellenberger Limestone—Cambro-Ordivician.

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, Jones.
Well Owner. Humble O. & R. Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Soil	0	10	10	Light shale	1480	1503	23
Sand	10	25	15	Lime	1503	1518	15
Red rock	25	30	5	Blue shale	1518	1675	157
Mixed gravel	30	35	5	Brown lime	1675	1705	30
Blue mud	35	39	4	Blue slate	1705	1740	35
Gray lime	39	40	1	White lime	1740	1765	25
Blue clay	40	120	80	Blue slate	1765	1848	83
Gray lime	120	155	35	Gray lime	1848	1860	12
Blue shale	155	170	14	Blue slate	1860	1875	15
Gray lime	170	172	2	Blue lime	1875	1881	6
Blue shale	172	235	63	Sand—water	1881	1899	18
Gray lime	235	239	4	Sand—water	1899	1904	5
Blue shale	239	254	15	Sandy lime	1904	1911	7
Gray lime	254	285	31	Blue slate	1911	1915	4
Blue slate	285	400	115	Sand—water	1915	1933	18
Gray lima	400	402	2	Blue slate	1933	1935	2
Blue slate	402	432	30	White lime	1935	1947	12
Gray slate	432	440	8	Blue slate	1947	1958	11
Blue slate	440	453	16	Lime	1958	1965	7
Sand—dry	456	468	12	Blue slate	1965	1973	8
Blue slate	468	485	17	Lime	1973	1978	5
Lime—sandy	485	490	5	Blue slate	1978	2001	23
Blue slate	490	530	40	Brown sandy shale	2001	2065	64
Gray lime	530	565	35	Blue slate	2065	2401	336
Blue slate	565	570	5	Sandy lime	2401	2409	8
Red rock	570	580	10	Blue shale	2409	2465	56
Blue slate	580	627	47	Sand—dry	2465	2491	26
Lime shell	627	631	4	Blue slate	2491	2495	4
White slate	631	645	14	Sand	2495	2502	7
Lime	645	654	9	Blue slate	2502	2520	18
Water sand	654	659	5	Sand—dry	2520	2526	6
Blue shale	659	692	33	Blue slate	2526	2550	24
Lime	692	694	2	Sandy shale	2550	2627	77
Sandy shale	694	728	34	White lime	2627	2638	11
Sand	728	746	18	Sandy shale	2638	2700	62
Blue shale	746	815	69	Blue slate	2700	2700	60
Lime shell	815	821	6	Black shale	2760	2850	90
Blue slate	821	838	17	Black lime	2850	2857	7
Sandy lime	838	855	17	Blue shale	2857	2920	63
Blue shale	855	880	25	Black shale and lime	2920	2947	27
White lime	880	890	10	Black lime	2947	2973	26
Brown shale	890	900	10	Blue shale	2973	2983	10
Blue shale	900	930	30	Black shale	2983	2995	12
White lime	930	953	23	Black lime	2995	3035	40
White slate	953	961	8	Black slate	3035	3063	28
Brown slate	961	970	9	Blue shale	3063	3067	4
Lime shell	970	974	4	Black lime	3067	3071	4
Broken water sand	974	995	21	Brown shale	3071	3104	33
Blue slate	995	1030	35	Blue shale	3104	3135	31
White lime	1030	1040	10	Black shale	3135	3140	5
Blue slate	1040	1075	35	Black lime	3140	3144	4
Lim e shell	1075	1078	3	Gas sand	3144	3148	4
Sand—dry	1078	1098	20	Black lime—sandy	3148	3160	12
White slate	1098	1115	17	Black lime	3160	3199	39
White lime	1115	1237	122	Brown shale	3199	3204	5
Sand	1237	1250	13	Sandy broken lime	3204	3253	49
Blue slate	1250	1325	75	Black shale	3253	3265	12
Lime shell	1325	1330	5	Black lime	3265	3285	20
Black shale	1330	1367	37	Sand—show gas and oil	3285	3290	5
Sand—dry	1367	1383	16	Black lime	3290	3309	19
Lime	1383	1394	11	Sandy lime	3309	3324	15
Sand—dry	1394	1402	8	Sandy shale	3324	3331	7
Lime	1402	1433	31	Black shale	3331	3446	115
Blue shale	1433	1440	7	Gray lime	3446	3464	18
Blue shale	1440	1450	10	Black shale	3464	3471	7
Blue shale	1450	1472	22	Lime shell	3471	3474	3
Blue lime	1472	1480	8	Oil sand	3474	3492	18

Total Depth—3492 feet.
Depth of oil sand below top of Black Lime—326 feet.
Initial Production—4500 bbls. daily.

CORRELATION SUMMARY.

0- 974—Canyon formation—Pennsylvanian.
974-2700—Strawn formation — Pennsylvanian.
2700-3148—Smithwick shale — Upper Bend—Mississippian.
-3148—Top of "Black or Marble Falls Lime."

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, Slayden. Well Owner, Prairie O. & G. Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Lime	0	35	35	Slate	1220	1340	120
White slate	35	195	160	Sand	1340	1385	45
Lime	195	250	55	Lime	1385	1415	30
Black slate	250	265	15	Slate	1415	1455	40
White slate	265	280	15	Sand	1455	1465	10
Black slate	280	310	30	Slate	1465	1633	168
Broken sand	310	370	60	Lime	1633	1685	52
Black slate	370	400	30	Slate	1685	1715	30
Lime	400	420	20	Lime	1715	1835	120
Black slate	420	435	15	Slate	1835	1855	20
Lime	435	450	15	Lime	1855	1870	15
Black slate	450	510	60	Sand	1870	1910	40
Lime	510	555	45	Lime	1910	1930	20
Black slate	555	560	5	Slate	1930	2560	630
Lime	560	565	5	Sand	2560	2650	90
Mud	565	605	40	White slate	2650	2860	210
Lime	605	625	20	Black slate	2860	2900	40
Slate	625	650	25	Lime	2900	2960	60
Lime	650	670	20	Shale	2960	3105	145
White slate	670	730	60	Lime	3105	3125	20
Lime	730	750	20	Slate	3125	3200	75
Black slate	750	840	90	Black lime	3200	3210	10
Lime	840	900	60	Black shale	3210	3229	19
Slate	900	940	40	Black lime	3229	3269	40
Lime	940	980	40	Shale	3269	3300	31
Slate	980	1020	40	Slate	3300	3420	120
Lime	1020	1040	20	Lime	3420	3435	15
White slate	1040	1140	100	Brown shale	3435	3442	7
Black slate	1140	1210	70	Oil sand	3442	3456	14
Lime	1210	1220	10				

Total Depth—3456 feet.
Depth of Oil Sand below top of Black or Marble Falls Lime—242.
Initial production—300 bbls. daily, which 2 weeks later increased to about 4500 bbls. daily.

CORRELATION SUMMARY.

0- 980—Canyon formation — Pennsylvanian.
980-2860—Strawn formation — Pennsylvanian.
2860-3200—Smithwick shale — Upper Bend—Mississippian.
-3200—Top of "Black or Marble Falls" Lime—Middle Bend —Mississippian.

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, S. V. Davis. Well Owner, T. & P. Coal, O. & G. Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Mud	0	5	5	Sand	825	835	10
Lime	5	45	40	Blue shale	835	1155	320
Blue shale	45	235	190	Lime	1155	1180	25
Lime	235	240	5	Blue shale	1180	1675	495
Blue shale	240	345	105	Lime	1675	1740	65
Lime	345	385	40	Light shale	1740	1845	105
Red rock	385	400	15	Blue shale	1845	2350	505
Blue shale	400	470	70	Sand	2350	2460	110
Lime	470	495	25	Dark shale	2460	2890	430
Sand	495	525	30	Lime	2890	2950	60
Blue shale	525	635	110	Black lime	2950	3000	50
Lime	635	695	60	Black shale	3000	3200	200
Blue shale	695	730	35	Shell—Oil and gas	3200	3215	15
Lime	730	825	95	Oil sand	3215	3221	6

Total Depth—3221.
Depth of oil sand below top of Black Lime—00 feet.
Initial Production — 1000-1200 bbls. daily.

CORRELATION SUMMARY.

0- 825—Canyon formation—Pennsylvanian.
825-2730—Strawn formation — Pennsylvanian.
2730-3200—Smithwick Shale — Upper Bend—Mississippian.
-3200—Top of "Black or Marble Falls Lime"—Middle Bend —Mississippian.

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, J. H. McClesky. Well Owner, T. & P. Coal, O. & G. Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Lime	0	35	35	Light shale	1180	1330	150
Yellow clay	35	45	10	Sand (salt water)	1330	1390	60
Blue shale	45	175	130	Light shale	1390	1615	225
Lime	175	215	40	Lime	1615	1635	20
Shale	215	276	61	Shale	1635	1660	25
Water sand	276	295	19	Sand	1660	1380	20
Light shale	295	354	59	Shale and lime	1680	1945	265
Lime	354	369	15	Sand (water)	1945	1967	22
Blue shale	369	380	11	Lime	1967	1990	23
Lime	380	395	15	White shale	1990	2470	480
Blue shale	395	460	65	Broken sand and shale	2470	2566	96
Lime	460	498	38	Sand—showing oil	2566	2572	6
Blue shale	498	520	22	Sand and shells	2572	2740	168
Lime	520	540	20	Black shale	2740	2920	180
Blue shale	540	570	30	Black lime	2920	2985	65
Lime	570	580	10	Black shale	2985	3035	50
Sand	580	590	10	Light shale	3035	3090	55
Blue shale	590	770	180	Black shale	3090	3204	114
Lime	770	800	30	Black lime	3204		
Light shale	800	1160	360	Oil sand	3427	3431	4
Sandy shale (water)	1160	1180	20				

Total Depth—3431.
Depth of oil sand below top of "Black Lime"—223.
Initial Production—1200 bbls. daily—Discovery well of district.

CORRELATION SUMMARY.

0- 580—Canyon formation—Pennsylvanian.
580-2740—Strawn formation — Pennsylvanian.
2740-3204—Smithwick shale — Upper Bend—Mississippian.
-3204—Top of Black or Marble Falls lime—Middle Bend—Pennsylvanian.

State, Texas, County, Eastland. District, Ranger. Well No. 1. Farm, F. Brewer. Well Owner, T. & P. Coal, O. & G. Co. Sheet No. 2.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Soil	0	20	20	Shale	1485	1510	25
Lime	20	50	30	Lime	1510	1520	10
Blue shale	50	200	150	Shale	1520	1555	35
Lime	200	210	10	Lime	1555	1565	10
Blue shale	210	225	15	Shale	1565	1940	75
Lime	225	235	10	Lime	1640	1650	10
Blue shale	235	245	10	Shale	1650	1660	10
Lime	245	255	10	Lime	1660	1695	35
Blue shale	255	315	60	Shale	1695	1702	7
Lime	315	324	9	Water sand	1702	1740	38
Shale	324	330	6	Shale	1740	2110	370
Lime	330	335	5	Gas sand	2110	2125	15
Blue shale	335	360	25	Shale	2125	2310	185
Lime	360	380	20	Sand	2310	2335	25
Shell	380	485	105	Shale	2335	2365	30
Sand	485	495	10	Sand	2365	2420	55
White shale	495	500	5	Shale	2420	2470	50
Shell	500	550	50	Shale	2470	2480	10
Blue shale	550	610	60	Sand	2480	2490	10
Water sand	610	620	10	Shale	2490	2550	60
Blue shale	620	630	10	Sand—broken	2550	2610	60
Water sand	630	650	20	Black shale	2010	2830	220
Blue shale	650	610	60	Black lime	2830	2865	35
Lime	660	665	5	Lime—broken—black	2865	2890	25
Blue shale	665	740	75	Black shale	2890	2960	70
Lime	740	760	20	Lime —broken—black	2960	2965	5
Brown shale	760	770	10	Brown shale	2965	3000	35
Shell	770	1210	440	Gray shale	3000	3010	10
Sand	1210	1230	20	Shale	3010	3041	31
Slate	1230	1260	30	Black shale	3041	3111	70
Brown shale	1260	1300	40	Black lime	3111	3140	29
Lime	1300	1305	5	Shale	3140	3170	30
Shale	1305	1450	145	Lime	3170	3185	15
Lime	1450	1485	35	Black shale	3185	3260	75

State, Texas. County, Eastland. District, Ranger. Well No. 1. Farm, F. Brewer. Well Owner, T. & P. Coal, O. & G. Co. Sheet No. 2.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Shell—lime	3260	3265	5	Brown lime	3274	3289	15
Black sandy shale	3265	3274	9	Oil sand	3289	3298	9

Total Depth—3298.
Depth of Oil Sand below top of "Black Lime"—178 feet.
Initial production—2200 bbls.

CORRELATION SUMMARY.

0- 485—Canyon limestone—Pennsylvanian.
485-2610—Strawn formation — Pennsylvanian.
2610-3111—Smithwick Shale—Mississippian—Bend (Upper) formation.
-3111—Top of Black or Marble Falls Lime—Mississippian—Middle Bend.

State, Texas. County, Comanche. District, Northern Comanche. Well No. 1. Farm, Knowles. Well Owner, Tex-Penn Oil Co. Sheet No. 1.

Formation.	From	To	Amt.	Formation.	From	To	Amt.
Clay	0	20	20	Sand	1060	1080	20
Conglomerate	20	40	20	White slate	1080	1100	20
White mud	40	50	10	Brown slate	1100	1175	75
Gravel	50	55	5	White slate	1175	1200	25
Lime	55	66	11	Black slate	1200	1220	20
White slate	66	93	27	Shell	1220	1230	10
Sand	93	110	17	White slate	1230	1300	70
Brown slate	110	160	50	Black slate	1300	1340	40
White slate	160	185	25	Brown slate	1340	1400	60
Lime	185	200	15	White slate	1400	1450	50
Sand	200	225	25	Shelly lime	1450	1500	50
Brown slate	225	275	50	White slate	1500	1540	40
Sand	275	300	25	Shelly sand	1540	1600	60
Black slate	300	350	50	White sand	1600	1650	50
Sand	350	390	40	Gray lime	1650	1680	30
White slate	390	395	5	Sand	1680	1720	40
White sand	395	440	45	White sand	1720	1730	10
White slate	440	445	5	Sandy lime	1730	1760	30
Sand	445	525	80	Sand	1760	1870	110
Slate	525	550	25	Brown shale	1870	1895	25
Lime shell	550	570	20	Lime	1895	1900	5
Slate	570	580	10	Sandy lime	1900	1940	40
Lime	580	600	20	Brown slate	1940	1950	10
Slate	600	605	5	Sandy lime	1950	2010	60
Lime	605	615	10	Black slate	2010	2030	20
Slate	615	645	30	Sand	2030	2050	20
Lime	645	655	10	Lime	2050	2080	30
Slate	655	705	50	Black slate	2080	2100	20
Sand	705	720	15	Sandy lime	2100	2120	20
Brown slate	720	800	80	Brown shale	2120	2140	20
White slate	800	850	50	Sandy lime	2140	2170	30
Brown slate	850	900	50	Sand	2170	2210	40
Lime	900	910	10	Black slate	2210	2215	5
White slate	910	940	30	Brown slate	2215	2430	215
Lime	940	950	10	Brown shale	2430	2460	30
White slate	950	970	20	Black slate	2460	2560	100
Sand	970	980	10	Gray lime	2560	2670	110
Brown slate	980	1050	70	Black lime—sandy	2670	2690	20
Sand	1050	1060	10				

Total Depth—2690 feet.
Depth Oil Sand below top Marble Falls Lime—130 feet.
Initial Production—4500 bbls.

CORRELATION SUMMARY.

0-2210—Strawn formation — Pennsylvanian.
2210-2560—Smithwick shale — Upper Bend—Mississippian.
-2560—Top of "Black Lime" or Bend Lime—Middle Bend—Mississippian.

The author is greatly indebted to William Kennedy, chief geologist of the Lone Star Gas Company, for many logs, for helpful suggestions in the preparation of this manuscript and for the careful criticism of the latter.

THE EXTENT AND INTERPRETATION OF THE HOGSHOOTER GAS FIELD.

By Walter R. Berger, *Winfield, Kansas.*

The Hogshooter Gas sand is the producing horizon of the field of the same name. This field is about twelve miles in length, and from one to one and one-half miles in width, extending north from the west-central part of Township 24 North, Range 14 East, Washington County, Oklahoma.

The Hogshooter gas sand lies directly upon the Boone Formation, which is a cherty limestone of Mississippian age, underlying this region at a depth ranging from 1200 to 1400 feet. The sediments immediately above this sand in this locality, the Cherokee shale, are considered Pennsylvanian in age. The sand varies greatly in thickness and pinches out at only a short distance to the east and west of the long axis of the field. The greatest thickness recorded in well records are near the center of the productive area. The maximum thickness recorded is 168 feet in well number 3 on the Taylor allotment in Section 18, Township 24 North, Range 14 East.

The sand horizon has been determined by means of several hundred records of wells drilled in this region, to be a continuous body of sand in a north-south direction, but very narrow and lenticular in the opposite direction. To the north it is productive in the Burgess oil field, located at the corner of Townships 26 and 27 North, Ranges 13 and 14 East. The Burgess field extends in a southeast-northwest direction and is about four miles in length. North of this oil field the sand is productive of gas in scattered wells, and in the small gas field two miles east of Copan, Oklahoma. Five miles farther north, the Vander Pool produced from this sand. This field compares with the Hogshooter field in its shape which is long and narrow, extending northward from Section 34, Township 29 North, Range 13 East, into Kansas.

To the south of the Hogshooter gas field the sand is not so easily determined as it is to the north. This is due principally to two causes. Firstly, the reliable well records of this area are scarce. Secondly, the Cherokee shale and the Boone formation

diverge[1] to the south and other beds come in between them. These intermediate beds thicken rapidly to the south, making it difficult to trace individual horizons in the well logs.

However, from the data available, it is considered that the Hogshooter sand takes an almost due south course. It is certainly the producing sand in the small oil field in the southwest corner of Township 23 North, Range 14 East. Six miles farther south a small gas field in Sections 35 and 36, Township 22 North, Range 13 East, and the oil field in the southwest corner of Township 22 North, Range 14 East, produce from this sand. The large gas field in the north central part of Township 21 North, Range 14 East, produces from a thick sand that seems to be the Hogshooter sand, even though the few good records show a thick shale to be present between the sand and the Boone formation.

As before mentioned the Hogshooter sand is very narrow. Throughout most of its extent it varies from one to five miles in width. Locally there are narrow extensions westward and eastward from the main body. In the Hogshooter Gas field the sand has a maximum recorded thickness of 168 feet, but does not appear in the logs of wells drilled four miles to the west and three miles to the east. In the Burgess oil field, where the axis extends nearly southeast—northwest, the thinning is even more rapid, from a thickness of at least 70 feet in wells near the center of the field to zero in wells one mile to the north and one half mile to the south. Likewise in the Vander Pool the sand thins from about 100 feet to zero in one mile to the east and in but a little greater distance to the northwest..

The known locations of the eastward and westward extensions from the main body are as follows:

(1)	Section 32 & 33	T. 28 N., R. 13 E.	thickness 34 feet.
(2)	Section 32	T. 27 N., R. 13 E.	thickness 17 feet.
	Section 5	T. 26 N., R. 13 E.	thickness
(3)	Section 32	T. 28 N., R. 14 E.	thickness 31 feet.
	Section 17	T. 27 N., R. 14 E.	thickness

[1]Relation of the Ft. Scott Formation to the Boone chart of southeast Kansas and northeast Oklahoma Journal of Geology, Vol. xxvi, No. 7, p. 619.

(4) Section 32 T. 24 N., R. 14 E. thickness 42 feet.

Section 6 T. 23 N., R. 13 E. thickness

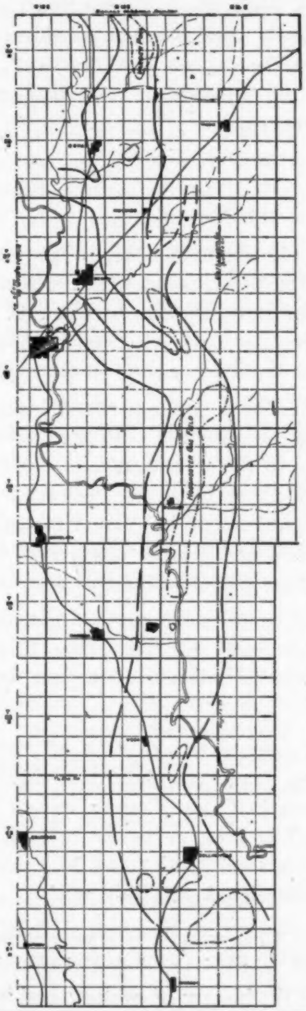
There are probably other extensions which have not been shown by the drilling. This is especially true of the southern part of the area, but as previously stated the sands there cannot be readily traced.

Two wells have been drilled by the Empire Gas & Fuel Company, one in the Vander Pool and the other in the south end of the Hogshooter gas field, from which very complete sets of cuttings were taken. A study of these cuttings shows that the Hogshooter gas sand is a light-colored sand, composed of rounded quartz grains, with a very small amount of Muscovite, pyrite and dark colored minerals. The size of the grains varies from 0.2 to 0.3 millimeters in the Hogshooter field, and from 0.3 to 0.6 millimeters in the Vander Pool.

All available data, especially the shape, thickness and irregular lenticularity of the sand in the east—west direction, lead to the conclusion that the Hogshooter gas sand must be the sand deposited by a large river along its course. This conclusion is strengthened by the fact that there was, at the time the sand was deposited, a topographical depression (which is interpreted as being an old river valley) in the area where the sand body is found. This depression extended north and north-westward as a trough which was present immediately prior to or during early part of the deposition of the Cherokee shales. This topographical depression or trough is evidenced by the great thicknesses of the Cherokee shale along this belt, in comparison with the thicknesses to the east and west. A stream coming from the region to the east of the granite hills of Kansas, which were undergoing erosion at this time, would come through this depression on its way to the pre-Cherokee basin, which lay to the south and east of the area under consideration.

The main body of the Hogshooter gas sand is interpreted as being deposited in the channel of the principal stream flowing southward through the pre-Cherokee valley. The narrow and comparatively thin eastward and westward extensions of the Hogshooter sand are believed to be deposits made by tributary streams in the lower parts of their courses.

Similar deposits are known at the surface in Central and Northern Missouri, where two main channels have been mapped[1]



Map Showing Extent of Hogshooter Gas Sand.

— - — Oil and Gas Fields Productive in Hogshooter Sand.

—— Extent of Sand.

× Wells with no sand present.

[1]Missouri Bureau of Geology and Mines, Vol. xii, 2nd series, pp. 91-106.

as the Warrensburg and Moberly Channels. These channels and their tributaries were made by streams flowing to the north and west from the old land mass in Southeast and Central Missouri. These channels were formed considerably later in Pennsylvanian time than the deposit just described, and at the time of their formation, the depositional basin had expanded far to the northward and westward.

Discussion.

Mr. Johnson.—I would like to ask Mr. Berger his opinion of the correlation of the Hogshooter sand with the sand southwest of Owassa. The original Burgess farm was in that region, and the original Tucker Farm also, and we have heard a good deal of the Burgess sand and the Tucker sand in those places.

Mr. Berger.—That is a locality about which I would not care to say anything definite, because the Cherokee Shales and the Boone formation diverge to the southward and other formations come in. Sandstones will come in to the southward and be productive in various parts and not to be related to each other. It would be hard to correlate and a large number of well records would be necessary in order to determine that accurately.

Mr. Decker.—I would like to ask Mr. Berger one question: Do you consider the possibility of that being a bar deposit? The irregularity of it seems to indicate it is a river deposit rather than a bar deposit.

Mr. Berger.—That suggestion would be all right provided we had a sand which we could correlate with this sand to the east or west but nowhere in Osage County, except a very few localities which are small in area, or to the east of this in Nowata County, do we have sands which can be traced over any large area that can be correlated with this sand.

Mr. Schuchert.—Mr. Chairman, it is a very important thing to be introduced to an old fossil river. I don't know that we have very many such things in the history of geology, and it is certainly very interesting to see how these things are working toward paleogeography and paleontology.

THE BEND SERIES OF CENTRAL TEXAS*

By Raymond C. Moore, *Lawrence, Kans.*

Introduction.

The Bend series of central Texas is a stratigraphic division of more than usual scientific and economic interest, first because it is an isolated portion of the Carboniferous separated some hundreds of miles from any outcrops equivalent to it and the problem of its exact age has never been satisfactorily solved, and secondly because of the important relation it has recently been proved to possess to the petroleum and natural gas deposits of north central Texas.

The general area of surface distribution of the Bend formations is well known. They outcrop on the east, north and west of the Llano uplift of early Paleozoic (Cambrian-Ordovician) rocks and to a certain extent on the south. The average width of the outcrop is about ten or twelve miles. The Bend is overlain by rocks of the Pennsylvanian or Cretaceous which are very evidently unconformable upon it, the unconformity being in some localities distinctly angular as well as erosional.

Lithologically, three subdivisions of the Bend have been recognized,[1] (1) a basal black shale, un-named, (2) a middle division of gray, blue or black limestone, known as the Marble Falls limestone, and (3) an upper division consisting of black and yellow shale, known as the Smithwick shale. The basal shale, absent in many localities, has a maximum thickness of about 50 feet, the middle division is approximately 500 feet thick in the region of outcrop, and the upper shale is probably not more than 400 feet thick.

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*By permission of the Roxana Petroleum Company, R. A. Conkling, Chief Geologist, F. B. Plummer, Chief of Texas Division, to whom acknowledgments are here made.

[1]Udden J. A. Baker, C. L., and Bose, Emil, Bulletin 44, Bureau Economic Geology and Technology, University of Texas, p. 42.

Description of the Bend Series.

The following description of the divisions of the Bend series is a summary of the writer's observations.

Lower Bend Shale.—A shale division at the base of the Bend series was first noted by Udden[1] who states that the maximum thickness attained is not more than 50 feet. This shale was observed by the writer at a number of points south and southeast of the town of San Saba and at one locality southwest of the town on Wallace Creek (Fossil collection 2). In most places it is a black, thin bedded, highly fissile shale with a prominent bituminous character. Good exposures of this phase of the basal shale are to be seen on upper Cherokee Creek in the southeast part of San Saba county, where, however, it is not more than 5 or 6 feet thick (see section below). It rests directly on the Ellenburger (Ordovician) limestone and is overlain conformably by the basal Marble Falls division which is here fossiliferous. At other points (as along the Bend-Cherokee road about 10 miles southwest of Bend) the shale is similar but the contact with the Ordovician is commonly observed by the slumping down of the shale.

South of San Saba, as on the San Saba-Chappel road just south of Simpson Creek, the basal shale is well exposed and is seen, perhaps, with its maximum thickness. The following section measured at this point shows the character of the shale, which it will be noted is not at all like the black, bituminous shale previously noted.

Section on San Saba-Chappel road, two miles southeast of San Saba, just south of Simpson Creek.

Bend Series.

Marble Falls Limestone.

3. Limestone, dark drab to black, fine-grained, thin-bedded, with well defined conchoidal or subconchoidal fracture, exposed ____ 20 ft.

Basal Bend Shale

2. Shale, drab gray to yellowish brown, sandy, with thin

[1]Udden J. A., Bull. 44, Texas Bur. Economic Geology and Technology p. 42.

beds of soft and hard brown sandstone, (Fossil collection 1.) ------------------------------------55 ft

Ellenburger Limestone (Ordovician)

1. Limestone, light bluish gray, massive to thin bedded, medium to rather coarse grained, crystalline, some beds cherty and non-fossiliferous---- --------------80 ft

This type of the basal shale is an importrant one for it is apparently developed over a considerable area where the shale has weathered. Many of the roads in the district southeast of San Saba follow the contact between the Marble Falls limestone and the Ordovician because the weathering of the basal Bend shale makes a smooth, though rather narrow pathway between the very rough, almost impassable limestone terranes on either side. Reeves,[1] who has made a more detailed areal examination of the Bend region, reports the basal shale, yellowish or drab and somewhat sandy, in the district south of Bend.

At some points, especially southeast of the Llano uplift, the basal shale is apparently lacking. Examination by the writer in the vicinity of Marble Falls and search by Paige and Girty[2] in the southern part of the Burnett quadrangle failed to show the basal shale, the Marble Falls limestone here resting directly on the Ellenburger. The exposure below the bridge at Marble Falls shows this contact clearly.

Marble Falls Limestone.—The middle or limestone division of the Bend is much the most prominent. Although drill records even fairly close to the region of outcrop show some shale and sandy beds in the Marble Falls limestone, the exposures are practically lacking in such materials. The formation is almost entirely composed of limestone but the kinds of limestone seem to include a rather wide range. Some of them, and these seem to have received most attention, are black and more or less noticeably bituminous; others are very light gray or almost white. Probably the average is somewhat between these extremes, dark gray, bluish, drab or dove-colored. Some brown beds, including

[1]Personal communication.

[2]Paige Sidney., and Girty, George H., Llano-Burnet folio, U. S. Geol. Survey, 1911.

especially dolomitized parts of the formation, have been observed. In texture there is also a wide variation, crystalline, sub-crystalline, fine-grained and very dense rocks occurring almost anywhere in the section.

Chemically the Marble Falls beds are very pure limestone except for the dolomitic horizons mentioned and the presence of more or less abundant chert. The bedding is generally rather thick, in some cases very massive. Thin bedded or even shaly zones have, however, been observed by the writer.

On account of the absence of some horizons which are very notably harder than others which might by their resistance form prominent topographic features and permit the development of somewhat continuous exposures, on account of the absence of such other prominent horizons as would permit accurate correlation of fragmentary sections, and on account further, of the folding and faulting about the Llano uplift which have displaced this limestone mass, it is an extremely difficult matter to make a continuous section across the Marble Falls division which will show definitely the position and nature of each of the lithologically varying horizons. However it is possible to make an approximation to a complete section.

On the southeast side of the Llano uplift the Marble Falls is excellently exposed along Colorado River, especially near the town of Marble Falls, the type locality. The lithologic variations are well shown here but there are very few fossils. A section measured by the writer here is as follows:

Section along Colorado River near Marble Falls, Texas.

Bend Series

Smithwick shale.

15. Shale, black, fissile, thin bedded: Upper portion partly concealed. ....35 ft

Marble Falls limestone

14. Limestone, dark gray to bluish, rather thin bedded, fine-grained, compact. ....17 ft
13. Limestone, black to very dark bluish gray, massively bedded ....31 ft
12. Limestone, brown to gray, rather evenly bedded, coarse grained. ....28 ft

11. Limestone, dark gray, subcrystalline, thin to massively bedded. Fossils ---------- 28 ft
10. Limestone, light and dark gray some beds mottled, chart in lenses and nodules, crinoid stems ---------- 24 ft
9. Limestone, black, evenly bedded, cherty ---------- 17 ft
8. Limestone, gray, rather coarsely crystalline, middle portion cherty ---------- 40 ft

Fault?

7. Limestone, gray, very uneven and irregular ---------- 17 ft
6. Limestone, black to dark bluish gray cherty ---------- 22 ft
5. Limestone, gray, to bluish, average to massively bedded, crinoid stems ---------- 60 ft
4. Limestone, dark gray to blue, fine grained, cherty -- 8 ft
3. Limestone, drab gray to bluish gray, with black matting, rather thin bedded ---------- 40 ft
2. Limestone, gray, mottled, somewhat brecciated and irregular ---------- 20 ft

Ellenburger Limestone (Ordivician)

1. Limestone very light gray, crystalline, very massively bedded, excellently exposed.

Total thickness Marble Falls limestone observed 352 feet.

In eastern San Saba and western Lampasas counties the Marble Falls limestone is exposed over a large area but it is very difficult to secure extended exposures across the section. A very high bluff on Cherokee Creek about 9 miles northeast of the town of Cherokee is typical of many smaller exposures and exhibits very well indeed the lower part of the Marble Falls limestone. The section measured at this point is as follows:

Section on Upper Cherokee Creek, nine miles northeast of Cherokee.

Bend series

Marble Falls limestone

Top of bluff

9. Limestone light gray, fine to medium grained, massively bedded, making a bold prominent jutting ledge ---------- 8 ft
8. Limestone, bluish-gray, weathering very massive,

with thin beds and lenses of white chert..........32 ft

7. Limestone, light bluish gray, like overlying beds but lighter color, weathering in thin flakes oblique to bedding. Noncherty. Makes bold scarp along the bluff. ....16 ft 6 in

6. Limestone, bluish drab, dense, fine grained, with conchoidal fracture, massively bedded. Chert in lenses and thick bands........................66 ft

5. Limestone, blue to light gray, fine grained, thin bedded, with wavy, irregular stratification. Becomes thicker bedded in upper portion. ....35 ft

4. Limestone, dark bluish drab, fine grained, thin bedded, hard, very fossiliferous (Fossil collection 3) 6 in

3. Covered interval ....2 ft

Basal Bend shale

2. Shale, black, fissile, bituminous (exposed)........5 ft

Ellenburger (Ordovician) limestone.

1. Limestone, gray, crystalline, massive

Total thickness of Marble Falls limestone exposed..158 ft

It is noteworthy in the section on Cherokee Creek that the base of the Marble Falls limestone is in no sense conglomerate or brecciated, although it is observed that the stratification of the lower divisions are somewhat uneven. The uniform presence of a basal conglomerate mentioned by Udden[1] was not observed by the writer, and as noted here, it is certainly not evident everywhere. From this it may be presumed that, as appears to be the case, where the Marble Falls rests directly on the Ellenburger limestone, a conglomeratic phase is present, but where it is underlain by the basal shale the conglomeratic or brecciated zone is not developed and the contact appears conformable. This should be noted in connection with the discussion of the age of the basal shale.

The middle portion of the Marble Falls limestone is excellently exposed on Rough Creek near the crossing of the Bend-San Saba road. The basal part of the section is as nearly as could be determined equivalent to the top of the last section (Cherokee Creek). Certainly Bed 2 of the following section which is very

[1]Udden, J. A., loc. cit. p. 42.

distinctive lithologically and which is marked by a well defined fauna, is higher than the uppermost bed of the Cherokee Creek section. The equivalent of Bed 2 was identified at other localities in San Saba county, as one and a half miles south of San Saba on the San Saba-Chappel road, proving that it is a rather widely developed and recognizable horizon. The section measured is as follows:

Section of the middle portion of the Marble Falls limestone, Rough Creek, San Saba County.

Bend series

Marble Falls limestone

12. Limestone, bluish gray, hard, crystalline, partly covered to top of hill ---------- 20 ft
11. Limestone, gray, crystalline, medium grained, hard thin-bedded, caps bluff ---------- 8 ft
10. Limestone, gray to yellowish, or mottled, partly dolomitic. Weathers to soft, somewhat chalky yellow rock, fossils (Fossil collection 8) ---------- 48 ft
9. Limestone, light gray, fine to medium grained, subcrystalline in beds 1 to 2 feet thick ---------- 10 ft
8. Limestone, black and mottled with gray, dense fine grained and very hard. Fossiliferous. (Fossil collection 7) ---------- 3 ft
7. Limestone, gray, fine grained, compact, massive, with numerous large *Chaetetes milleporaceus* (Fossil collection 6) ---------- 12 ft
6. Limestone, yellowish, soft, shaly ---------- 1 ft
5. Limestone, yellowish, gray, fine grained, dense, subconchoidal fracture, thin bedded, containing fossil fragments (Fossil collection 5) ---------- 4 ft
4. Limestone, gray, massive, medium grained, subcrystalline cherty ---------- 25 ft
3. Limestone, gray, massive or weathering in thin even beds, subcrystalline, cherty, the chert occurring in thin lenses and beds ---------- 28 ft
2. Limestone, mottled gray or drab, and yellowish gray, weathering yellow dense, fine grained, with subconchoidal fracture, beds rather uniform in thickness, average 4 in. to 1 ft., in marked contrast

with adjacent beds. Fossiliferous. (Fossil collection 4) ....12 ft

1. Limestone, bluish gray, medium to fine grained, very massive, weathering in rounded surfaces......58 ft

Base of section, level Rough Creek.

Total thickness of Marble Falls limestone exposed 229 feet

The upper part of the Marble Falls limestone and the contact with the Smithwick shale division are best studied in the vicinity of Bend, on Colorado River and Cherokee Creek. A section measured from a point about one mile west of the town of Bend, from the Colorado River south to a high bluff on Cherokee Creek shows both the Smithwick shale in its typical development, and the upper Marble Falls limestone.

Section of Smithwick shale and upper Marble Falls limestone, Colorado River west of Bend to point on Cherokee Creek, to the South.

Bend series

Smithwick shale

10. Shale, olive to grayish green, clayey to sandy, thin bedded, weathering readily (Fossil collection 14)..100 ft

9. Shale (black, fissile, bituminous, the lower part with thin beds of black limestone..............115 ft

Marble Falle limestone

8. Limestone, black to bluish black, thin bedded, hard subconchoidal fracture Fossiliferous (Fossil collection 13) ....10 ft

7. Limestone, dark bluish gray or dovecolored, subcrystalline, hard, beds 6 in. to 1 ft. thick .... 5 ft

6. Limestone, light yellowish gray, dolomitic, contains fossil fragments and molds (Fossil collection 12).. 2 ft

5. Limestone, dark bluish gray, medium grained, subcrystalline,, very massive, containing chert nodules and fossil fragments .... 4 ft

4. Limestone, light gray, nodular uneven stratification, but massive, weathering in grayish green thinner beds .... 9 ft

3. Limestone, yellowish gray, thin bedded to shaly, lower part covered ....14 ft

2. Limestone, dark bluish drab to mottled, thin bed-

ded, hard, dense, subconchoidal fracture---------38 ft

1. Limestone, gray, medium grained, very massive weathering in flakes oblique to bedding and giving smooth surfaces ------------------------------80 ft

Total exposed thickness of Smithwick shale 215 ft.

Total exposed thickness of Marble Falls limestone 162 feet.

Careful study of the sections last described, that near Bend and that on Rough Creek, and of the intervening country, indicates that the only overlapping is the top of the Rough Creek section and the base of the Colorado River-Cherokee Creek section.

The sections on upper Cherokee Creek, Rough Creek and lower Cherokee Creek together give the most nearly complete information concerning the Marble Falls limestone as a whole in the San Saba county portion of its outcrop. So far as field examinations, carried west nearly to Brady, show it is not possible elsewhere to obtain long or closely adjacent exposures.

Smithwick Shale.—The upper division of the Bend is very well exposed southeast of the Llano uplift in the vicinity of Smithwick, Marble Falls and other points on Colorado River and tributary streams. Near the town of Bend and for a number of miles upstream the exposures are unexcelled. The formation is certainly more than 300 feet in thickness northwest of Bend and as the top of the formation has suffered an unknown amount of erosion here, the original thickness of the formation can only be estimated. Probably it is somewhat less thick in the vicinity of the uplift than farther distant, for there was apparently some diastrophic movement in this region after the Bend deposition and before the Strawn sedimentation.

The outcrop of the Smithwick follows the Colorado and San Saba Rivers north and west from Bend, or rather these streams have followed the outcrop of the shale, easily cutting their valleys in the non-resistant shale.

Fauna of the Bend Series.

The collections of fossils made by the writer may be referred to three horizons, those recognized lithologically as the three main formational subdivisions of the Bend series. The following list shows the species identified and the portion of the series in which they have been found:

FAUNAL LIST OF THE BEND SERIES OF TEXAS.

*Textularia sp			x		
Fusulina sp		x			
COELENTERATA					
Hadrophyllum aplatum Cummins					x
*Zaphrentis gibsoni White			x		
Xaphrentis n. sp.			x		
Zaphrentis sp. 1 & 2			x		
Amplexus corrugatus Mather			x		
Lophophyllum profundum (E.&H.)			x	x	
Campophyllum torquium (Owen)			x	x	
Campophyllum sp.			x		
Axophyllum rude (White&St. John)			x		
*Acervularia sp			x		
Michelinia n. sp.				x	
Michelinia eugeneae White?			x		
Chaetetes milleporaceus E. & H.			x	x	
VERMES					
Tubicola? gen et sp.?			x		
ECHINODERMATA					
Cromyocrinus n. sp.			x		
Eupachycrinus sp. 1 & 2			x		
Crinoid stems	x	x	x	x	x
Archeocidaris mucronatus M. & W			x	x	
Archeocidaris norwoodi Hall?			x		
Archeocidaris sp. 1 & 2			x		
BYROZOA					
Fistulipora carbonaria Ulrich			x		
Fistulipora n. sp.			x		
Stenopora n. sp. 1			x		
Stenopora n. sp. 2			x		
Stenopora sp.			x		
*Lioclema sp.			x		
Fenestella compressa Ulrich			x		
Fenestella modesta Ulrich			x		
Fenestella sp. cf. F. multispinosa Ulrich			x		
Fenestella sp. 1, 2, 3, 4			x	x	
Polypora sp. 1 & 2			x		
Septopora biserialis (Swallow)			x		
Septopora sp.			x		
Pinnatopora sp.			x		
Rhombopora attenuata Ulrich			x		
Rhombopora lepidodendroidea Meek			x		
Rhombopora persimilis Ulrich			x		
Rhombopora tabulata Ulrich ?			x		
Rhombopora sp.			x		
Cystodictya n. sp.			x	x	x
Cystodictya lineata Ulrich ?			x		
Cystodictya sp.			x		
Prismopora n. sp.			x		
Glyptopora n. sp.			x		
BRACHIOPODA					
Lingula sp.					x
Lingula albapinensis Walcott	x	x	x		

Orbiculoidea batesvillensis Weller?			x		
Orbiculoidea caneyana (Girty)		x			
Orbiculoidea n. sp.	x	x			
Orbiculoidea sp.				x	x
Rhipodomella pecosi (Marcou)			x	x	
Orthotichia schuchertensis (Girty)			x		
Schellwienella? sp.			x		
Orthotetes? kaskaskiensis (McChesney)			x		
*Derbya sp.			x		
Chonetes choteauensis Mather			x	x	
Chonetes laevis Keyes					x
Chonetes mesolobus N. & P.			x		
Chonetes n. sp. 1		x	x		
Chonetes n. sp. 2					x
Productus coloradoensis Girty ?			x		
Productus cora D'Orbigny		x	x	x	
Productus inflatus McChesney		x	x	x	
Productus morrowensis Mather			x		
Productus nanus M. & W. ?			x		
Productus parvus M. & W.			x		
Productus sp.			x	x	
Pustula bullata Mather			x		
Pustula globosa Mather			x		
Pustula moorefieldana pusilla (Girty)			x	x	
Pustula nebrascensis (Owen)			x		
Pustula punctata (Martin)			x		
Pustula sublineata Mather?			x		
Pustula sp.	x				
Avonia arkansana (Girty)				x	
Avonia? arkansana multilirata (Girty)			x		
Avonia n. sp.				x	
Marginifera ingrata Girty ?			x		
Marginifera spendens N. & P. ?			x		
Marginifera sp.			x		
Marginifera ? sp.			x		
*Aulosteges n. sp.			x		
Leiorhynchus carboniferum Girty	x	x			
Pugnax utah (Marcou)			x		
Dielasma bovidens (Morton)?			x		
Dielasma sp.			x		
*Spirifer cameratus Morton			x		
Spirifer increbescens Hall?			x		
Spirifer marcoui			x		
Spirifer rockymontanus Marcou			x	x	
Spirifer n. sp.			x	x	
Spiriferina kentuckiensis (Shumard)			x		
Spiriferina spinosa (N. & P.)			x	x	
Spiriferina transverse (McChesney)			x	x	
Hustedia miseri Mather			x		
Squamularia perplexa (McChesney)			x	x	
Squamularia transversa Mather?				x	
Ambocoelia planiconvexa (Shumard)	x	x			
Athyris sp.			x		x
Composita subquadrata (Hall)?		x	x		
Composita wasatchensis (White)			x		
Composita sp.			x		
Cliothyridina hirsuta (Hall)			x		

Cliothyridina subamellosa (Hall)?					x
PELECYPODA					
Solenomya n. sp.			x		
Sanguinolites sp.			x		
Nucula rectangula McChesney			x		
Leda bellistriata (Stevens)			x		x
Leda bellistriata attenuata (Meek)?			x		x
Leda nasuta Hall?			x		
Parallelodon sp.			x		
Parallelodon ? sp.			x		
Leptodesma spergenense robustum Girty?			x		
Pinna sp.			x		
Conocardium n. sp.					x
Leiopteria n. sp.			x		
Leiopteria sp. n. var.			x		
*Pseudomonotis sp.			x		
Myalina subquadrata Shumard?					x
*Myalina pernifromis Cox			x		
Schizodus depressus Worthem			x		
Aviculopecten n. sp.				x	
Aviculopecten sp.		x			
Acanthopecten carboniferus (Stevens)?				x	
Acanthopecten n. sp.			x	x	
Streblopteria herzeri (Meek)			x		
Caneyella n. sp.			x		
Modiolus n. sp.			x		
*Pleurophorus occidentalis Meek & Hayden?			x		
*Pleurophorus sp.			x		
Conocardium obliquum M. & W.			x		
GASTROPODA					
Bellerophon n. sp.				x	x
Bellerophon wewokanus Girty				x	x
Bellerophon sp.			x		
Euphemus carbonarius (Cox)				x	
Bucanopsis meekiana (Swallow)					x
*Bleurotomaria turbiniformis M&W					
Pleurotomaria sp. (1) (2, 3)		x	x		
Worthenia ? sp.			x		
Phanerotrema n. sp.					x
Murchisonia sp.			x		
Bembexia nodomarginata (McChesney)					x
Euomphalus n. sp.					x
Schizostoma catilloides (Conrad)				x	
Turbo n. sp. 1					x
Turbo n. sp. 2					x
Sphaerodoma ? sp.			x		x
Meekospira peracuta (M. &. W.)				x	x
Bulimorpha ? sp.					x
Holopella sp.			x		
Playtyceras parvum (Swallow)				x	
CEPHALOPODA					
Orthoceras sp. 1, 2, 3, 4					x
†Stearoceras gibbosum (Hyatt)			?		
Metacoceras walcotti Hyatt				x	

Nautilus sp. 1, 2				x	
Cyrtoceras sp.				x	
Gastrioceras compressum Hyatt				x	x
†Gastrioceras entogonum Hyatt			?	?	
Gastrioceras kingi (Hall & Whitefield)?			x		
Gastrioceras sp.					x
Glyphioceras n. sp.		x			
Glyphioceras cumminsi (Hyatt)		x			
Glyphioceras incisum (Hyatt)		x			
Paralegoceras n. sp.			x		x
Paralegoceras sp.					x
TRILOBITA					
Griffithides scitulus M. &. W.			x		
Griffithides scitulus major n. var.				x	
Griffithides ? sp.			x		
Phillipsia missouriensis Shumard?			x		
PISCES					
Edestus minor Newberry					?
Helodus ? sp.		x			
Fish tooth		x			
*Reported by Girty.					
†Reported by Hyatt.					

Lower Bend Shale.—Fossils are not abundant at any point in the lower Bend shale, so far as investigated. However, fossils are obtained from at least two localities. One collection was made from the shale beneath the Marble Falls limestone on the San Saba-Chappel road, two miles southeast of San Saba. The fossils are weathered out of the shale and are well preserved.

Fauna of lower Bend shale, southeast of San Saba, (1)

Leiorhynchus carboniferum (Girty)
Leda bellistriata (Stevens)
Glyphioceras n. sp.

A second collection was obtained from calcareous nodules in the black shale on Wallace Creek about 9 miles southwest of San Saba. A number of individual specimens were obtained here but almost all belong to a single species, *Ambocoelia planiconvexa* (Shumard).

Fauna of lower Bend shale southwest of San Saba (2)

Plant fossil (Cordaites?)
Lingula albapinensis Walcott
Orbiculoidea n. sp.
Ambocoelia planiconvexa (Shumard)

It will be noted that all of these species are common to the

overlying beds in the lower part of the Marble Falls limestone.

Marble Falls Limestone.—The collections from the middle division of the Bend Series range from the very base nearly to the top and show clearly the nature of its fauna. The collections are also somewhat widely distributed geographically. Collections from the lowermost Marble Falls are from upper Cherokee Creek (3) from the middle portion chiefly on Rough Creek near the crossing of the Bend-San Saba road (4-8) and from a tributary of Wallace Creek about 12 miles southwest of San Saba (9-10). The upper beds of the Marble Falls limestone are represented by collections on the Bend-Chappel road about 2 miles east of Chappel (11), and on Colorado River about three quarters of a mile west of the bridge at Bend (12, 13) which come from the very top of the division. The composition of the faunas is shown in the preceding general faunal table. It will be observed that the great majority of species recognized in the Bend fauna come from the Marble Falls limestone.

A collection made by F. B. Plummer on the Bend-San Saba road from beds of limestone immediately overlying the basal shale contains the following species.

Fauna of basal part of Marble Falls limestone southeast of San Saba.

Fusulina sp.
Crinoid stems
Lingula albapinensis (Walcott)
Leiorhynchus carboniferum (Girty)
Leiorhynchus carboniferum polyplerum (Girty)
Dielasma sp.
Ambocoelia planiconxexa (Shumard)
Composita sp.
Cliothyridina sp.
Aviculopecten sp.
Loupteria? sp.
Pleurotomaria aff. perhumerosa
Orthoceras cf. Sp. A. Girty (Wewoka)
Orthoceras sp.
Glyphioceras cumminsi (Hyatt)
Glyphioceras n. sp.
Glyphioceras sp.

Smithwick Shale.—The uppermost formation of the Bend series is found to contain fossils at certain horizons. The collections of the writer were made chiefly along the excellent exposures near the junction of the Bend-San Saba and the Bend-Cherokee roads about a mile west of the town of Bend, in the lower part of the olive gray shale near the middle of the formation. Although some hundreds of specimens in all were secured, the number of species is not very large. In the main they are distinct from those of the Marble Falls limestone. The differences in composition, however, are the natural result of the marked change in the sediments and the ingress of additional Pennsylvanian elements. The gradual transition in kind of sediment which is witnessed by the interbedded black limestone and black bituminous shale at the top of the Marble Falls limestone is sufficient indication of the conformable sequence of the Smithwick shale.

Analysis of the Bend Fauna.

A critical study of the Bend fauna makes evident its transitional position between the typical faunas of Mississippian age and those most characteristic of the Pennsylvanian. The fauna as a whole is different in many respects from the faunas of approximately equivalent horizons which have previously been described, for there is in the Bend a rather large proportion of new species. Yet a sufficient number of forms are found which are common to other formations of known geologic age to make certain the position of the Bend fauna.

It is noteworthy that some species which have previously been rported only from Mississippian rocks occur in the Bend even as high as the Smithwick shale. All of these and other species which are very closely related to Mississippian genera and species are persistent or residual elements in the Bend fauna. It is rare that the fauna of a new geologic horizon does not contain some elements of the preceding geologic division, as here illustrated. The incoming or proemial faunal elements are, however, most important factors in the determination of the age of a series. Hence the occurrence of common and characteristic Pennsylvanian types in the Bend indicates that the series belongs to the Pennsylvanian. The associated Mississippian

elements, the characteristics of the Pennsylvanian fossils, as well as the position and other stratigraphic relations of the series show that the Bend belongs in the early portion of the Pennsylvanian.

The transitional nature of the Bend fauna is shown to a greater or less degree in each of the classes of invertebrates. The following list includes the most important representatives of the Mississippian:

Residual Mississippian Element of the Bend fauna

Amplexus corrugatus
Acervularia sp.
Cromyocrinus n. sp.
Rhombopora attenuata
Rhombopora persimilis
Rhombopora tabulata?
Cystodictya lineata?
Presmapora n. sp.
Glyptopora n. sp.
Orbiculoidea caneyana
Orthotetes? kaskaskiensis
Productus inflatus
Productus parvus
Pustula moorefieldana pusilla?
Avonia arkansana
Avonia arkansana multilirata?
Leiorhynchus carboniferum
Leiorhynchus carboniferum polypleurum?
Spiriferina spinosa
Spiriferina transversa
Composita subquadrata?
Cliothyridina hiruta
Cliothyridina sublamellosa?
Schizodus depressus
Caneyella n. sp.
Bembexia nodomarginata
Gastrioceras kingi?
Glyphioceras cumminsi
Glyphioceras incisum

Characteristic Pennsylvanian fossils which are found in association with these may be listed as follows:

Proemial Pennsylvanian Element of the Bend Fauna.

Fusulina sp.
Zaphrintes gibson
Lophophyllum profundum
Campophyllum torquium
Axophyllum rude
Chaetetes milleporaceus
Eupachycrinus sp.
Eistulipora carbonaria
Fenestella modesta
Septopora biserialis
Rhombopora lepidodendroides
Rhipomella pecosi
Orthotichia schuchertensis
Chonetes laevis
Chonetes messolobus
Pustula nebrascensis
Pustula punctata
Aulosteges sp.
Dielasma bovidens?
Spirifer cameratus
Spirifer rockyemontanus
Squamularia perplexa
Ambocoelia planiconvexa
Leda bellistriata
Pseudomonotis sp.
Acanthopecten n. sp.
Pleurophorus sp.
Bellerophon wewokanus
Bellerophon n. sp.
Euphemus carbonarius
Bucanopsis meckiana
Schizostoma castilloides
Meekospira peracuta
Platyceras parvum
Metacoceras walcotti
Paralegoceras n. sp.

Griffithides scitulus
Griffithides n. sp.
Edestus minor

In conclusion it may be observed that the Mississippian element is most prominent in the lower part of the Bend series and is progressively less important in the upper portions. Conversely the Pennsylvanian elements become more characteristically developed in the middle and upper parts of the series with the ingress of a larger number of species belonging to the new period. If the presence of Fusulina near the base of the Bend may be relied upon, the paleontologic evidence agrees with the stratigraphic observations, that the Bend is a geologic unit and that above the unconformity at its base, it is all to be referred to the Pennsylvanian.

Correlation of the Bend Fauna

Even casual study of the fossils from the Bend calls attention to the similarity in composition of this fauna to that of the Morrow group of Arkansas and Oklahoma recently described by Mather[1]. Not only is a like intermingling of residual Mississippian and incoming Pennsylvanian forms observed in the latter fauna but very many of the species, including a number which have to the present time been reported only from the Morrow, are common to the two. Some of the examples of distinctive Morrow species which are found in the Bend, as *Productus morrowensis, Chonetes choteauensis* are numerous and very typical. Some of the most characteristic Mississippian genera which were reported from the Morrow fauna, as the blastoid, Pentremites, and the peculiar bryozoan, *Archimedes*, are, however, not found in the Bend. Nevertheless, careful comparison of the two faunas leaves no question concerning the homotaxial equivalence of the Morrow group and the Bend. The position of the Morrow beds with reference to a fossil flora of known age (early Pottsville), the Pennsylvanian elements in its invertebrate fauna, and the occurrence of an important unconformity

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[1]Mather, Kirtley F., The fauna of the Morrow group of Arkansas and Oklahoma, Den. Univ. Sci. Bull., vol. XVIII, pp. 59-284 (1915).

beneath it makes clear the Pennsylvanian age of the group in spite of the Mississippian forms among its fossils. On the basis of the invertebrate fauna which is the subject of this study, the Bend series may be correlated with the Morrow and referred to the early Pottsville division of the Pennsylvanian. The very great unconformity at the base of the Bend is thus equivalent to the important erosion break which everywhere in the Mississippi basin separates the Pennsylvanian from underlying strata.

Recent study of the Wapanucka limestone of Oklahoma has shown the presence in that formation of many characteristic fossils of the Morrow group, and according to Mather[1] the Wapanucka is without question equivalent in age to the Morrow. Many of the species are likewise common to the Bend fauna, and although the latter is not known to contain the forms such as *Pentremites* and *Archimedes* which are most suggestive of the Mississippian, the Wapanucka may likewise be correlated with the Bend.

The presence in the Bend of a number of fossils identical with or very closely related to species occurring in the Caney and Moorefield shales of Oklahoma and Arkansas respectively, is of interest and without doubt of stratigraphic significance. Since the Caney and Moorefield species occur chiefly in the lower portion of the Bend, the possible equivalence of the lower Bend to these formations was carefully considered by the writer. If the correlation of the Caney by Ulrich[2] and Woodworth[3] to the Pottsville is correct the contemporaneity of the Caney and Bend at least in part may be admitted, but if the Caney, which Girty's[4] studies indicate is very closely related to the Moorefield is properly placed in the late Mississippian, it is believed that the Bend species which are common to the Caney and Moorefield

[1]Mather Kirtley F., Pottsville formations and faunas of Arkansas and Oklahoma, Journal Am. Acad. Science, vol. 43, 1917, pp. 133-139.

[2]Ulrich, E. O., Bull. Geol. Soc. Am., vol. 22, p. 476 (1912)

[3]Woodworth, J. B., Bull. Geol. Soc. Am., vol. 23 p. 457 (1912).

[4]Girty, Geo. H., Fauna of the Caney shale of Oklahoma, U. S. Geol. Survey Bull. 377 (1909).

must be regarded as persistent forms which with other Mississippian genera and species lived in the central Texas basin until early Pennsylvanian time. In this connection it is to be observed that there is no evident indication of any stratigraphic break between any portion of the lower Bend and the upper, that some Moorefield species, as *Bembexia nodomarginata,* appear to have survived into the Smithwick horizon, and that such a characteristic Pennsylvanian form as *Fusulina* seems to have been introduced in the Bend waters as early as the very base of the Marble Falls limestone. Hence the Caney and Moorefield faunas are to be regarded as closely related but somewhat antecedent to the invertebrate fauna of the Bend series.

Comparison with the Pennsylvanian faunal horizons of Kansas as described in the papers by Beede and Rogers[1] makes it evident at once that there are no formations present in that state which are nearly so old as the Bend series. The fauna of the Cherokee shale, the basal Pennsylvanian formation in the Kansas region contains none of the residual Mississippian elements which are so prominent a feature in the faunas both of the Bend series and of the Morrow. On the contrary the Cherokee may be traced stratigraphically and faunally into Oklahoma and is correlated with a horizon very far above the base of the Pennsylvanian.

Summary.

1. The Bend series of central Texas consists of three lithologic subdivisions, a basal shale about 50 feet thick, a middle limestone (Marble Falls), 400-500 feet thick, and an upper shale (Smithwick) about 400 feet thick.

2. Each of the subdivisions are more or less fossiliferous, about 175 species in all having been collected by the writer.

3. The fauna contains an important residual Mississippian element which progressively disappears in the upper part of the series, and a clearly defined incoming or proemial Pennsylvanian element which becomes more prominent with the ingress of additional Pennsylvanian species in the upper beds.

4. The fauna of the Bend shows that the series may be

[1]Beede, J. W., and Rogers, A. F., Coal Measures Faunal Studies; Kans. Univ. Geol. Survey, vol. IX, p. 318. (1908).

correlated with the Morrow group of Arkansas and Oklahoma, and the Wapanucka limestone of Oklahoma.

DISCUSSION.

Dr. Moore: In reading Dr. Girty's paper yesterday, Dr. White brought out the opinion of one of our most able paleontologists with regard to the correlation of the Bend fauna. He recognized three faunas, that of the Bend Shale, the Marble Falls Limestone and the Smithwick Shale, regarding the lower-most as Mississippian and the two upper as Pennsylvanian. Mr. Matteson then mentioned Dr. Wellers' determination of Bend fossils as Mississippian.

Dr. Weller, I know, has some Bend fossils which he said were largely new and Mississippian in appearance. Apparently later information from Dr. Weller—and there is no one of our American paleontologists whom I regard personally or professionally higher than Dr. Weller—based on other material leads him to regard the fossils as Pennsylvanian without doubt.

With regard to the correlation and interpretation of the fauna, I may say that the lower Bend shale fauna, as I found it, though not a large one, contains contrary to the statements of Dr. Girty's paper, species which were without any question common to the fauna of the lower Marble Falls limestone and furthermore, some of the species found in the lower Bend shale are among the most abundant of the species in the basal part of the Marble Falls limestone. Therefore I cannot see how the lower shale can be Mississippian and the Marble Falls limestone of a different geological age.

Without question the Bend fauna contains fossils which closely resemble Mississippian types. Indeed, when I was working in the field I felt for a time that I had to do with a very late Mississippian fauna. There are a number of genera and many species which have been described previously only from Mississippian strata. Some of the types are common Mississippian forms, but associated with them, ranging through the Marble Falls—there are undeniably Pennsylvanian forms. There is no doubt, then, from the presence of these Pennsylvanian forms in the fauna marking the coming in of Pennsylvanian life that the formation as a whole must be regarded as Pennsylvanian prob-

ably earliest Pennsylvanian in age, and this notwithstanding the presence in the fauna of Mississippian forms. Such a mingling is observed in many other transitional formations. However, such characteristic Pennsylvanian things as our Fusulinas have not been found in the Bend, so far as I am aware, which might be an indication of its very early position in the Pennsylvanian.

This work we have done on the fossils of the Bend is, I feel, important and perhaps a more adequate basis for statements from a paleontological standpoint than other collections which I believe have been available.

Chairman: We are under obligation to Dr. Moore for this very valuable contribution. He is from Kansas, but he also finds it necessary to work in Texas. The paper is open for discussion.

Mr. Schuchert: Mr. Chairman, as you allowed me last evening to read Dr. Girty's paper, I did that with a great deal of pleasure, and I will say that there appears to be a fundamental difference between Dr. Moore and Dr. Girty.

I think we must all have the highest respect for Dr. Girty's work. For over twenty-five years he has been a specialist of Pennsylvanian fauna; he has collected them from all over this whole country of ours; he has comparative material from Europe; and when he says a thing, I think that we must pay a good deal of attention to it.

Now Dr. Moore says that he hasn't seen Fusulina from the Bend. Dr. Girty says he has a primitive form of Fusulina from the Marble Falls. So far as Marble Falls being Pennsylvanian, we agree on that. He says there is not a single species in common between that unnamed lower shale and the higher two members—not a single thing. There are two Goniatites——Goniatites crenistria and Goniatites striatus—European species which occur high in the European Carboniferous, which occur in the lower Bend and do not occur in the Marble Falls. There is a totally different Ammonite-like thing in the Marble Falls, Paralegoceras. So you see Dr. Girty has the basis, so far as I can see it, on which to say that there is a totally different fauna in the lower shale when contrasted with the upper formations. Remember, I am not giving you any of my own ideas: I am just giving you what

I have read. Now further than that I cannot go, but I rather think the evidence is a little bit against Dr. Moore.

Mr. Moore: With regard to the basal shale, I will merely say that true Goniatites crenistria is not contained in my collection. I did find another species of Goniatite for which. I believe, the generic name of Glyphioceras should now be employed, and the species of Leiorhynchus mentioned by Dr. Girty, both in the basal Bend shale of the Marble Falls limestone. I have abundant material which will demonstrate that, and therefore the difference, I think, is largely due to lack of material from the basal shale.

Mr. Schuchert: Let me add one more fossil, one more remark to show how easy it is to go astray. There is a certain fossil that occurs in the Mississippian that some of you may know as Paleacis, a little coral. If somebody had brought me a Paleacis alone without anything further, I should unhesitatingly have said, "We are in the Mississippian," and yet that occurs in all the upper part of the Marble Falls with these Mississippian Carboniferous fossils.

Mr. J. A. Udden: I am naturally interested in this discussion. I am no paleontologist, but I have seen a good deal of the Bend and I know it pretty well lithologically. When I heard some of the observations in our papers yesterday, I was almost ready to inquire, what is the evidence of an unconformity in the Bend besides that of the paleontological record? It seems to me that if there is such an extensive unconformity, that it would be likely that it should show up somewhere in the exposures. I have never been able to see anything exposed that would indicate an unconformity. Of course I know that sometimes those unconformities are obscure or they may not even show up at all. There is one shortcoming of some of our paleontologists, and that is that they do not have time to see enough of the fields that they discuss, and I think that this is an important point to bring out; that it is necessary to spend a good deal of time in the field so that one knows exactly what one is talking about.

Now Dr. Moore has evidently done that—I know he has done it—and looking at the lithological characteristics of the Bend I want to call your attention to a similarity between the Bend and the lower most Pennsylvanian farther north. It is

a small thing that may not signify much, but I find that even these inexplicable little structures that we find sometimes, lithological characteristics, are quite characteristic even over long distances if we examine them well and understand them fully. There is one little structure in the Bend, in the upper shale of the Bend, that is very peculiar. I think it is a fossil. It was, at one time. It is something like what was once described in the New York reports as Spirophyton cauda-galli. We find a fossil of this resemblance in the basal Pennsylvanian on the Mississippi near Rock Island, in a black limestone above "Coal number 1," and this coal is now believed to be of Pottsville age. Unless we have a great many fossils, tables of them, to discuss, and tables of them determined by more than one paleontologist, so that we can have a sort of consensus of opinion—unless we can do that, I think that very often some of these mechanical fossils, or whatever we may call them, may count as much as, for example, species that are "somewhat similar" to this and that other species. So I have for some time had the belief that the Bend belongs above the Mississippian, and I was very much interested to hear the discussion both today and yesterday. I am not so sure that the Bend will prove to be the very base of the Pennsylvanian. I have certain reasons that I hardly dare to tell why I think that the Bend is an equivalent to a formation which we have out in West Texas that we call the Dimple Formation. That Dimple Formation has certain peculiarities that are similar—I mean lithological peculiarities—that are similar to lithological characters in our Bend, as we have found quite recently in making a very close study of the lithology of the Bend. Now, under the Dimple we have about 2000 feet of Pennsylvanian rocks in the western part of the State.

Mr. Moore: I may add that where I have seen the basal shale it is thin but rather uniform in thickness, and it is a rather striking thing that a shale formation where I have seen it apparently conformable with the Marble Falls should have preserved from erosion between the Mississippian and the Pennsylvanian. If there was a hiatus here it is the kind of a formation which one would not expect to persist, and the absence of the lower shale at Marble Falls and other points is easy to explain, it seems to me, on the basis of an overlap.

Mr. Schuchert: Just for the humor of the occasion, let me

say that this fossil that Dr. Udden referred to, this caudagalli, means "rooster's tail." It looks like a rooster's tail, and is really the burrow of a worm. It usually burrows in a horizonal manner, but sometimes in a spiral manner. Caudagalli, or rooster's tail, or Taonurus caudagalli, doesn't indicate anything, because I know it in the Silurian and in the Devonian, and we know it in the Miocene.

Mr. J. A. Udden: I know it even later than that.

Mr. David White: Dr. Udden is referring to what is more commonly referred to in Geological reports as "Spirophyton." It is extremely abundant just above the Mississippian in the vicinity of Vinita, Oklahoma.

Dr. Girty, in his paper says that the limestone and the upper shale are Pennsylvanian, while he suggests that the lower shale may correlate with the lower 500 feet, paleontologically, of the Caney Shale. Now Dr. Girty seems inclined to regard the Caney Shale as transgressing from the Mississippian into the Pennsylvanian.

One thing more I wish to add in confirmation of Dr. Udden's statement regarding the age of the Morrow, with which the Bend—the upper Bend at least, including the limestone and the upper shale—is correlated in agreement by at least four or five paleontologists present, and that is doing well. So far as concerns the age of the Morrow, with which Dr. Udden and others are correlating the limestone and upper shale of the Bend, Dr. Udden is absolutely right.

The Morrow is not lowest Pennsylvanian; it is paleo-botanically—which of course proves it—upper middle Pottsville, or as is more probable, lower upper Pottsville.

SULPHUR MINING

By JOHN L. HENNING, *Lake Charles, La.*

When one has lived with the subject as long as I have with this, there is no one thing in it that stands out as particularly interesting. The subject of sulphur in its relation to the Salt Domes of the Gulf Coast of Louisiana and Texas is a large one, and without previous preparation, a condensed statement by me, along geological lines, would be difficult.

One interesting fact about sulphur is its absence in commercially available quantities,—even with the Frasch process for mining.

There are few places in the world where some sulphur will not be found. Many people believe where there is a little sulphur there must be more. Its existence in small quantities, unlike oil in that respect, does not justify assuming it must be there in commercially profitable quantities.

It does occur in vast quantities in many parts of the world in a complex compound to harass the miner and refiner of nearly every metal used in commerce. Its existence, however, in this form provides a wide field of opportunity for the future petroleum geologist and mining engineer.

The extraordinary sulphur situation at this time justifies a comment from a purely business standpoint.

As far back as 1892, we investigated the West Texas sulphur deposits and concluded at that time that twenty years hence they might be commercially available as a supply of elementary sulphur. About the end of that period some friends invested in some of these prospects and then asked my advice as to their value. I suggested at that time that ten years hence they might be profitable to exploit *for sulphur.* About three years of that time has yet to pass and I see nothing to warrant a change of my opinion, except perhaps to add a few years more to the prediction.

Geologists should exercise especial precaution in reporting on these prospects, as commercial conditions are an important

factor at this time. Another misleading indication to the layman is the existence of sulphur water, which is world-wide. As Mr. Wrather remarked yesterday, it seems closely associated with the Ellenberger. I believe the Salt Domes of the Gulf Coast country are also closely related to the Ellenberger. I made this suggestion to an eminent geologist last night and he said he would not undertake to refute it. You will notice that I began my theories on gulf coastal geology where the present art of drilling wells stops, hence it is not easy to prove or disprove.

Many prominent geologists have visited the Sulphur Mine in Louisiana and all have evinced great interest in its occurrence. I would usually take them up on top of a bin of sulphur 60 feet high covering an area the size of this city block and its smooth surface with the assistance of a nail, seemed to inspire one to demonstrate by graphic methods how it happened.

The long tedious years of experimentation with the Frasch process before reaching a commercially successful status, tended to dull my interest in how it occurred. We had enough to keep us very busy in devising means of how to get it up where, as Mr. Frasch used to say, "we can spat on it."

For several hundreds of years sulphur has been one of the major questions of anxiety for nations, even to the extent of precipitating war. It may be interesting to some of you to know that the sudden swoop of Italy on the Turks in Tripoli a few years ago was primarily due to the existence of sulphur in Tripoli, and thereby hangs a tale too long to relate here.

Previous to 1904 sulphur was produced in commercially profitable quantities in only one place in the world, namely, Sicily. The Frasch process brought the United States to the front place and since that time the Louisiana mine could easily have produced the entire world's consumption.

The romantic history of sulphur has led many people to enter the game and all had fallen by the wayside until deposits similar to the one in Louisiana were discovered and the Frasch process applied.

The war changed the whole sulphur situation. After Italy declared war against Austria and before declaring war against Germany, nearly all the surplus sulphur from Sicily found its

way into Germany, also a large number of mines in Sicily became flooded or caught on fire.

The United States was then called upon to supply England with sulphur for munitions purposes. As early as 1916, the possibility of increased demand for elementary sulphur became apparent and the United States Geological Survey was urged to encourage the development of pyrite mines in the United States in order to conserve for emergency purposes the *elementary* sulphur supply. The chaotic conditions in this country produced by our entrance into the war, made progress slow in clarifying the sulphur situation. In August, 1918, it became clear that if the war should last a year or two longer, the supply of sulphur above ground would be inadequate for a proper degree of safety and active steps were being taken to meet the situation. From a normal pre-war annual consumption in the United States of about 300,000 tons it was estimated the consumption for 1919 would be not less than 2,000,000 tons. At this time the Louisiana mine was producing at the rate of 1,400,000 tons per year which was its maximum, but could not be guaranteed, hence the necessity for the Government stimulating production elsewhere. Now that the war is over there is an immediate over-production and precaution is necessary in dealing with the subject.

It may be of interest to know that it is entirely possible that if Captain Lucas had not geologized "spindletop" and given us low-priced fuel, Sulphur Mine, Louisiana, might yet be what it was for thirty years previous to 1901—The graveyard of hopes and money. I know that it was a deciding factor that induced Mr. Frasch to sever his connection with the Standard Oil Company in 1902. I made an investigation of the fuel oil situation for him in the latter part of 1901 and reported that so far as *his* fuel requirements were concerned, the spindletop supply was permanent. He immediately said "all right, that settles it." In April, 1902, he came back to Beaumont and said "I am free; I have severed my connection with the S. O. people and now let's get busy." I was included in his sulphur mine program, but for certain reasons remained at Beaumont to handle the fuel oil situation. Conditions soon changed and the problem became one of *wells* rather than of fuel and I closed out the oil business and

went to Sulphur Mine to "produce" wells, and how well we succeeded may be stated by saying that over five hundred have been drilled there since that time.

Discussion.

Mr. Woodruff: This problem, as we know, is very closely related to the oil proposition in the Gulf Coast country, therefore, I gave it some thought while working in that country. My first interest dates farther back and to another region. Back in 1907, at the suggestion of Dr. Hayes, I investigated a sulphur deposit at Cody, in Wyoming, where sulphur is actually depositing. Our geology generally goes back to the time when we can't actually see things, but there at Cody in the Shoshone River canyon, (called Stinking Water because the hydrogen sulphide is escaping and floating down the canyon) the sulphur is precipitated from the escaping gas. The strata which closely relate to the sulphur deposit are a sandstone overlaid by limestone. The hydrogen sulphide bearing water, working up through the sandstone, comes in contact with the limestone and forms gypsum in very fine crystals and the chemical reaction precipitates the sulphur. In Bulletin 340 of the United States Geological Survey, there is a description of the Cody deposits. In that report Mr. Chas. Palmer has given some of the probable chemical reactions for the deposition of the sulphur from the hydrogen sulphide.

Later I visited the sulphur and oil fields at Toyah, Texas, where I found geological conditions the same as at Cody, only they are decadent and not active. The sulphur has almost ceased deposition though there is a slight escape of hydrogen sulphide. There is very good evidence of the hot springs cones. Along the hills where there is a limestone dipping to the east, the limestone is dissolved and caverns are formed in many places where the hydrogen sulphide bearing water has percolated through. It seems that the same action has gone on there exactly as at Cody. In many places there are nothing but flat white gypsum cones, but in other places there is the gypsum with the sulphur enclosed. So much for conditions as they have been actually observed and interpreted. I wish to apply the principles deduced from these observations to the coastal domes.

I later saw some well cuttings and secured data from Bryan Heights, one of the sulphur bearing salt domes of the Gulf Coast country. To my mind, the essential conditions at Cody and Toyah are the same in the salt domes. There is a porous limestone through which water has percolated; there are some hydrogen sulphide gases still escaping but these gases may not be actual present seep but gas liberated by the drilling. But even if so, the principles apply the same because these gases were stored by the earlier action. There are so many of the other sulphur gases it is pretty hard to distinguish, but anyway from some of the Gulf Coast mounds there has been hydrogen sulphide escaping. It seems to me that this hydrogen sulphide, working through the limestone cap on the salt dome, has produced the same reaction in the past it is now producing at Cody, Wyoming, where it is precipitating the sulphur. The hot circulating acidic waters have dissolved caverns in the limestone and concurrently the sulphur has been precipitated in some of the openings where it is now found associated with gypsum which is simply the altered limestone. Apparently the sulphur has not come down immediately in all places but has been carried along to limestone pores in some places. I think we have the same conditions at Hoskins Mound, though we may not be able to prove this.

I think, then, that the sulphur in the salt domes is the result of circulating water in which the limestone cap was deposited due to the reaction in the different zones. I think that a subsequent action was the hydrogen sulphide gas percolating through the limestone, dissolving it and concurrently the chemical reactions precipitating the sulphur in the irregular cavities in which it is found. I have made the prophecy that you will not find sulphur in the salt domes in which you have no limestone cap over them. You will not find it in those in which the hydrogen sulphide gases were not active enough to have considerable action.

Chairman: Mr. Woodruff, I am not clear in my mind as to what you consider the origin of the hydrogen sulphide, where it comes from.

Mr. Woodruff: We have never been able to solve that. I know there are intrusions near the sulphur beds at Cody, Wyom-

ing and in the south end of the Bighorn Basin at Thermopolis, Wyoming. We know it is hardly probable they come from those intrusions, however, and I have never been able to solve in my own mind, the origin of the hydrogen sulphide. It has been suggested that it comes from the disassociation of gypsum in the strata, but that has not been proved. So while there are those two principal suggestions made as to its origin—namely, from the intrustions of igneous rocks, and from the disassociation of the various salts, chiefly perhaps the gypsum. I have never been able to give a satisfactory explanation of the origin of the hydrogen sulphide, but we know the gases have escaped and are escaping.

The fact is underground waters would be still liquid although at a temperature that would melt wrought iron, and would dissolve any substance with which they come into contact to a greater or less extent. A little stoichometry will show that water in contact with any sulphur-bearing mineral would yield hydrogen sulphide.

Mr. Woodruff: There is an article on that in one of the bulletins of the Geological Survey, I don't recall the number just at this time.

Mr. Plummer: I have performed certain experiments that have a bearing on this problem. It is well known in organic chemistry that if you decompose any organic compound, the products given off are carbon dioxide, ammonia, sulphur dioxide, and water. In the laboratory in the common methods of organic analysis the substance is decomposed, the carbon dioxide and water are absorbed and weighed, and the nitrogen is collected in a tube and measured. All the gases are first passed over copper oxide and remove the sulphur. In all analysis this provision is made to take care of the sulphur that is produced, for it is well known that sulphur is a common decomposition product.

Therefore it has always seemed to me that the sulphur and sulphur gases of the Gulf Coast may all have come from the decomposition of buried organic matter that is everywhere present in the Gulf Coast, especially in the carbonaceous clays. Now I took some of the carbonaceous muds obtained in drilling on the Gulf Coast and also some peat from a coastal marsh and treated

them by the methods used in organic analysis and as I expected obtained a goodly quantity of sulphur. Then I experimented to see if the sulphur could be given off by natural process. For this I placed the sediments in a tall cylinder, covered them with salt water, added a little acid, and left it in a warm place. Bubbles were very slowly given off which contained carbon dioxide and hydrogen sulphide. Both sulphur dioxide and hydrogen sulphide when dissolved in water give an acid reaction. A little of the sulphur acid in water increases greatly the solubility of lime to form the bicarbonate.

If hydrogen sulphide is passed into a calcium bicarbonate solution, calcium hydrogen sulphide is obtained.

The calcium hydrogen sulphide soon breaks down into calcium carbonate, sulphur, and water, and sulphur is precipitated upon standing, a process that may easily be demonstrated in the laboratory.

Now in the salt domes all these necessary ingredients are present, for there are quantities of organic matter in the Gulf Coast sediments. Acid water is ascending and circulating around the salt domes, and capping the salt are layers of lime and dolomite. As the acid water ascends and dissolves the limey cap rock, sulphur is precipitated, and in greater quantities where the most lime goes into solution; that is, right in the crevices and the pores of the cap rock itself.

I think this the simplest explanation exactly in line with what our former speaker, Mr. Woodruff, has stated. So far as I know he is the first man to offer an adequate explanation that laboratory experimentation proves out excellently.

The decomposition of organic matter forms sulphur dioxide and hydrogen sulphide that passes upward as acid water or gas into the carbonate zone of the cap rock. The acid waters are neutralized by the excess of alkaline carbonates, and sulphur is precipitated. Naturally this process goes on only in those salt domes where a calcareous cap rock is present and where conditions are favorable for the ascension of hydrogen sulphide waters or possibly the free gas. I do not know of any sulphur around a Gulf Coast salt dome where a calcareous cap rock is not present.

Chairman: Mr. Plummer, I wish to ask in regard to the principle enunciated, as to how it is reconciled with the tectonic theory, the tectonic origin?

Mr. Plummer: The tectonic process, that is, the upward intrusion of a salt plug domes up the surrounding strata. Around the dome hydrostatic pressures are set up so that hydrogen sulphide bearing waters tend to flow upward into the dome and perhaps even to escape in springs and flowing wells. These water channels make it easy for the acid water to come in contact with the calcareous cap rock zone. Still better, if later tectonic movements occur, and we know there were later movements in salt domes, the cap rock might be further fractured and new passage ways opened up for the circulation of waters. The more the cap rock is fractured by earth movements the more easily will the sulphur water circulate, and the more sulphur will form.

According to the tectonic theory the history of a salt dome is as follows: First, deep burial of the salt bed; second, folding into a syncline and squeezing under great and deep-seated pressures; third, the flowage of the plastic salt mass upward as a result of the great lateral squeezing; fourth, the bowing up of the strata above it; fifth the recrystallization of the salt and the forming of the zones of pure salt below, and above impure salt, gypsum, lime, and dolomite in order of their solubility in their mixed solution, all this being attended and aided by circulation of ground waters; sixth, the deposition of more sediments accompanied by further earth movements resulting in the producing of the cap rock and the furnishing of new passage ways for the circulating acid waters; seventh, precipitation of sulphur. Sulphur, in the history of a salt dome is one of the last products formed. Does that answer your question?

Chairman: I wanted to have some conception of your idea as to the gradual uplifting of this salt, or whether sudden instrusions or something like that may have taken place during a long period of time. Was it periodic or continuous?

Mr. Plummer: It was continuous as long as the great isostatic pressure lasted. But just as in the forming of mountain ranges, I presume it was greater in certain epochs and nearly

quiescent in others. There are unconformities in salt domes just as in other greater domes, and at least some evidence which may enable us to correlate movements in the salt domes with the great crustal movements observed in the younger mountain ranges in Mexico.

Mr. Fuller: I would like to ask what relation, if any, the small oil wells near Toyah have to the sulphur deposits.

Mr. Woodruff: I am glad Mr. Fuller asked that question because I consider the conditions which control the accumulation of oil at Toyah, Texas, very extraordinary. I was called for an examination of that field. Geologically, there is a general northeast-southwest trending uplift, with the strata dipping to the east where the oil is found. A thick limestone which outcrops in the Rustler Hills to the west, shows this dip—I think perhaps as much as 15 degrees, isn't it? We will assume that that is not very far off, anyway. These waters have worked through the strata and have dissolved the limestone and formed caverns. There are some surface caves that can be entered now; one must be half as large as this room. I don't see any reason why we shouldn't assume there are others under the ground. The action of the waters have left hot spring cones for fifteen or twenty miles along the strike of the limestone. In a very sketchy way these are the general geological conditions. It seems to me that there is a small amount of oil in the strata, that the waters have circulated through the strata and dissolved out the caverns and have also carried a little oil and the oil has been collected in these various caverns. I think that theory is borne out by the fact that a well put down—as I recall it, one well was put down to a depth of 217 feet and found only a few barrels of oil, and another 100 feet approximately, from there found nothing, and another one, in a triangle, a little further away, found just a few barrels of oil at 400 or 500 feet. Another well at several hundred feet in depth found a little oil. All of these were in a radius of one-eighth of a mile. The pockets were exhausted—I call them "pockets" because I think of them in that way—but the deposits of oil were exhausted in a few days. To my mind, there are underground caverns partly filled, or probably completely filled, with oil. This accounts for the oil at different depths. The oil is a peculiar light yellowish oil, a rather unusual

oil. I don't know that the action of the sulphur water on oil would produce any peculiar results but it might alter an ordinary oil to the peculiar yellowish oil found in this field, but thats just a suggestion. Therefore, I think in that area along Rustler Hill, there is oil only in little irregular pockets, which were old caverns in the limestone, which has now been converted largely, or almost wholly, to gypsum.

Mr. J. A. Udden: I was very much interested to hear the remarks of Mr. Woodruff. I found in another well very clear evidence of cavernous openings that had been filled with Cretaceous material as far down as 800 or 900 feet below the surface. How deep were these oil pockets?

Mr. Woodruff: As I recall, one oil pocket was found at about 1700 feet.

Mr. J. A. Udden: I can't help mentioning this in corroboration of Mr. Woodruff's statement, that in one of the Troxel wells where I examined samples very carefully and we found Cretaceous fossil after having gone through part of the Permian Formation. I did not understand it quite at the time, because I did not know all of the features of the country out there. I may mention that I have found, similarly Carboniferous fossils down about 500 feet in the Niagara in the northern part of the United States. I think it is very clear that caverns sometimes will be excavated quite far down in limestones, and this is certainly a very interesting occurrence. I have always wondered how it was that oil gave out so quickly in that well, and that there was really such a supply to start with.

Mr. Woodruff: I was recently talking with one of the men who was drilling in that neighborhood. They have recently drilled quite a little in that vicinity and have obtained wells that produce perhaps two or three barrels each at an average depth of 135 feet. This party said he was to put down twenty more. I simply wish to point to this as a possible indication that the oil is more widespread than would be indicated by the previous remarks, and also that there may be more than the one particular horizon or cavity.

Mr. Wrather: Mr. Woodruff, is it your impression that leaching of the limestone is due to the action of thermal waters?

Mr. Woodruff: The waters were probably thermal. There is no direct evidence of this. They were acid waters, anyway. The hydrogen sulphide passing through the water gives an acid water. There is a little hydrogen sulphide escaping at the present time. In digging into some cuttings, my hands were cut and I went over to a little pool to wash them,—I am telling you this to show that the water is still hot,—a man standing near there said, "Don't wash your hands in there, it will take the skin off." He exaggerated that a little, but the water from which hydrogen sulphide is coming now is slightly acid. I think it would have the same cavern-forming effect whether it was hot or not, but I imagine they were hot.

UNCONFORMITIES IN OKLAHOMA AND THEIR IMPORTANCE IN PETROLEUM GEOLOGY

By Edward Bloesch, *Okmulgee, Oklahoma.*

The unconformities in Oklahoma have never been studied fully and carefully. Their importance for the petroleum industry is such, that a few observations and ideas shall be published as a contribution to this question and an incentive to further study of the proposition.

In virgin territory the petroleum geologist has to figure the structure from surface exposures eventually supplemented by data from water wells, coal mines or other comparatively shallow excavations. In drawing his conclusions as to the structure of the oil bearing strata, he has to assume, where there is no reason against it, that the oil sands are parallel to the surface strata. This assumption is based on the fact that the sediments were originally laid down level, or, to be more accurate, in layers parallel to the surface on which they were laid down with a tendency to level up this surface. This rule applies more closely to water sediments than to sub-aerial deposits. Deep sea deposits are with rare exceptions laid down parallel like the leaves of a book, due to the ocean bottom being practically level. Closer to shore there are irregularities partly due to the relief of the sea bottom, coral reefs, and bars, partly to the actions of currents and waves. Sometimes a place of shallow water gets filled up entirely and becomes a land surface on account of a slight receding of the ocean and erosion sets in. Certain irregularities in the bedding are called false or cross bedding varying from deposits at a certain regular angle in river deltas to very irregular wavy layers due to action of currents and waves. Cross bedding occurs in Oklahoma in numerous places in the sandstone formations and is in particular a very common feature of the Permian Red Beds. While cross bedding is ofen very troublesome to the geologist it shall not be considered further as it does not produce unconformities in the sense this term is generally used.

A typical angular unconformity is formed as follows: The bottom of the ocean is raised above sea level and the strata tilted or folded. Erosion sets in and either accentuates the relief or

wears the surface down eventually to a peneplain. After while the land is submerged again often suffering a new tilting and the sea encroaches upon the land depositing sediments, which overlap the old land surface more and more. The oldest stratum of the new series of sediments is generally a conglomerate or a sandstone, particularly where the waves of the encroaching sea are the agencies which wear down the old land surface. These base conglomerates generally make a good reservoir for oil and gas. On account of the angular unconformity these substances may be able to migrate into this new formation from strata originally separated by a great thickness of impervious material.

Of the two agencies which generally cause an unconformity, namely, elevation above sea level with the consequent interruption of sedimentation and beginning erosion, and tilting or folding, one may be absent. It happens sometimes that the strata are raised above sea level without being tilted and later submerged the same way. Erosion may or may not contribute to the unconformity, but at any rate the result consists of two series of sediments separated by a period without sedimentation, with the strata of both series practically parallel to each other. For many problems of structural geology such unconformities need not be considered. As the petroleum geologist has often to deal with dips of a fraction of one degree he ought to pay attention to these unconformities in his work. It is very unlikely that the ocean floor could emerge and then again be submerged without receiving a very slight tilting.

If strata are folded or tilted under the ocean, this takes place without interrupting the sedimentation. This forms an unconformity, which can not be seen at a certain place, as the change in the angle of the beds is gradual. We will find however, that two key horizons separated by several hundred feet of sediments may lay at quite an angle to each other. In other words the intervening series thickens or thins from one point to another in a degree which has to be considered in drawing conclusions from the surface structure as to the subsurface structure.

Unconformities in Oklahoma.

The unconformities of importance to the petroleum geologist in Oklahoma can be classified according to their age as follows:

1. Unconformity at the base of the Cretaceous
2. Unconformities in the Permian
3. Possible unconformity at the base of the Permian
4. Unconformities in the Pennsylvanian.
5. Unconformities near the contact of Pennsylvanian and Mississippian.

In the Arbuckle Mountains, where older formations are exposed, there are no unconformities reported between the Mississippian and the Ordovician, which is the oldest oil producing horizon in the Mid-Continent Field[1].

Taff[2] reports a slight unconformity in the Cretaceous between the Comanche and Gulf series in southern Oklahoma.

All the Tertiary and Quarternary formations of Oklahoma lay unconformable on older formations, but as they do not furnish any key horizons, these unconformities are of no interest in petroleum geology.

1. The unconformity at the base of the Cretaceous.

The Cretaceous in the south part of Oklahoma is laid down on a peneplain, as is clearly shown on the Tishomingo and Atoka[3] folios of the U. S. Geol. Survey. It overlaps all the older formations from the Permian down to the Pre-Cambrian granite.

We do not know just how far the Cretaceous covered Oklahoma before it was removed by erosion, as the remaining Cretaceous strata do not indicate that they have been deposited very close to the shore. Most likely more than half of the state has once been covered by Cretaceous sediments. For the western part as far east as a line from Alva to Hobart this is proven by remnants, which are shown on the geological maps of Oklahoma. They are really more numerous than shown on the maps, but in many places they cover only a very small area. One occurrence just north of the town of Sayre may be mentioned as occurring further south than any shown on the geological maps.

The question of how many of these Cretaceous relics are

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[1]S. Powers: Demonstration at the meeting of the American Association of Petroleum Geologists, Oklahoma City, 1918.

[2]Joseph A. Taff: Tishomingo Folio U. S. Geol. Survey No. 98, 1903.

[3]Joseph A. Taff: Atoka Folio, U. S. Geol. Survey No. 79, 1902.

actually in place needs closer investigation. In most of the occurrences, which the author has visited in Custer, Washita and Beckham Counties, which are well exposed, the Cretaceous is not in place. These deposits consist of angular boulders and pieces of white and yellow sandstone, fossiliferous limestone and light gray or yellowish shale, all of Cretaceous age and also of red sandstone and shale which belongs to the Permian and possibly Triassic. These blocks and boulders of different material, which sometimes have a diameter of over 10 feet are intermingled and do not show any signs of transportation by water. The only way these deposits can be explained by the writer is, that after deposition of the Cretaceous streams dissected the land surface cutting deep canyons, in which the walls, formed by Red Beds and Cretaceous rocks, caved in. Even at present the Cretaceous relics seen by the author do not cap the highest hills and generally near by deposits of Permian in place are at a higher elevation. Just at what time the erosion of the canyons and the deposition of the boulders in their present location took place we do not know. A close study of these deposits might reveal fragments of upper Cretaceous or Tertiary and would add considerably to our knowledge of the geological history of Oklahoma. One exposure, where these features can plainly be seen is in Sec. 34, T. 12 N., R. 19 W., and two or three other places were observed in Beckham County north of North Fork of Red River.

2. Unconformities in the Permian.

The larger part of the Permian of Oklahoma was deposited in a shallow sea as is proven by irregularities of deposition (cross bedding), by layers of Gypsum and rock salt and also by the presence of land fossils. The latter do not prove that any of the Permian beds are land deposits. They only show the proximity of land for instance in the Wichita Mountains. The nature of the Red Beds however is such that occasionally there must have been land surfaces at least of local extent. On account of depositional irregularities it is not easy to distinguish local unconformities due to emergence from cross bedding which took place under sea cover. To the author's knowledge no land surfaces with following unconformities have yet been proven in the Permian area of Oklahoma.

3. Possible unconformity at the base of the Permian.

The Permian is conformable to the Pennsylvanian in northern Oklahoma and also in Texas, but overlaps older formations in the Wichita Mountains and also around the west end of the Arbuckle Mountains. At the base of the Permian there is a coarse sand in these latter places, which makes a good reservoir for oil and the unconformity enables the oil to migrate from tilted Pennsylvanian strata into this basal sandstone and from it back into sandstones regularly interstratified in the Permian. The accumulation of oil in the pools at Gotebo, Lawton, Healdton and Wheeler has been explained in this manner by the authors who studied the subject[1], but additional information on the problem is still desirable.

The different writers seem to think that there is an unconformity between Permian and Pennsylvanian in the region of the Arbuckle-Wichita Mountains. It is quite likely that this is really the unconformity, in the Pennsylvanian, which marks the folding of the Arbuckle Mountains and that where Permian rests uncomformably on older deposits it is just the gradual overlap of a series of upper Pennsylvanian and Permian on the folded and truncated older formations. The 500 feet of blue shale reported from the Healdton field between the unconformity and the Red Beds (Wegemann and Heald loc. cit.) are likely upper Pennsylvanian.

4. Unconformities in the Pennsylvanian.

Local unconformities probably occur in the Red Beds of Pennsylvanian age just as they do in the Permian Red Beds.

Fossil plants are fairly common in various parts of the Pennsylvanian area, particularly in the lower strata and indicate the possibility and even probability of emergence of some of the ter-

[1]C. H. Wegemann and K. C. Herald: The Healdton Oil Field, U. S. Geol. Survey Bull. 621 B, 1915.

C. H. Wegemann and R. W. Howell: The Lawton Oil and Gas Field, Oklahoma, U. S. Geol. Survey, General Bull. 621 G., 1915.

See also C. W. Shannon: Petroleum and Natural Gas in Oklahoma, Part 2, Okla. Geol. Survey Bull. 19, 1917.

ritory long enough to grow a vegetation. While some of the fossil plants indicate by their state of preservation that they have been transported for a considerable distance, others are very well preserved. The shales which accompany the Henryetta coal contain fine specimens of ferns in T. 12 N., R. 13 E. As this locality is over fifty miles from the Ouachita Mountains, we come to the conclusion, that some part of the Pennsylvanian area in or near Okmulgee County must have been elevated above sea level for a long enough period to allow a fern vegetation to grow. This happened during the upper part of the Muskogee Group. All the extensive coal beds are indications of shallow sea if not land and the vegetation which formed the coal probably grew on land or in coastal swamps. The common occurrence of ripple marks also proves slight emergence above set level, at least of short duration.

As emergence means an interruption of deposition, local unconformities are bound to be present in the Pennsylvanian of Oklahoma. They seem however to be inconspicuous as most of them have escaped the attention of the geologists. Heald[1] report an unconformity in the Ralston Group northwest of Pawhuska. The writer knows of only one angular unconformity, which can be seen plainly exposed. In the north part of Sec. 9, T. 16 N., R. 15 E. along the Midland Valley railroad a shale exposure is dipping north at a perceptible angle and is overlain by a sandstone ledge, which strikes north and south and dips west. A similar unconformity between shale and sandstone, possibly the same as the one mentioned was observed near the center of section 21 of the same township.

Unconformities of a nature which mainly assert themselves in changes of thickness are quite common in the Pennsylvanian of Oklahoma. A general thickening of the formations to the south has been reported ever since oil men and geologists have started to trace certain horizons, but only very recently some accurate information on these changes in thickness was obtained.

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[1]G. C. Heald: Geologic Structure of the Northwestern part of the Pawhuska Quadrangle, Oklahoma, U. S. Geol. Survey Bull. 691, c. 1918.

The Cushing Anticline

Already in 1914 F. Buttram[1] published a structure contour map of the Bartlesville sand in the Cushing Field, which varies considerably from the surface structure. Unfortunately some of his well log correlations are incorrect and as he did not mention the well records used for the structure contours this work could not be checked up. In 1917 Beal[2] published structural contour maps of the Cushing Field showing the surface structure on the Pawhuska limestone, the structure on the Layton sand, the Wheeler sand and the Bartlesville sand. The structure of the producing sands is quite different from the surface structure. Local irregularities of the sand structures are partly due to inaccurate logs and partly to irregularities of the sand surface of depositional but not structural nature. The subsurface structure maps show that the folding in each of these horizons is stronger than in the one above. This means that the lower strata were folded before the upper ones were deposited. Folding took place at least four different times since the Bartlesville sand was laid down. Not only is the main folding stronger but cross folds are more developed in the lower sands than at the surface. Good well records are too scarce to decide if there are angular unconformities between these different horizons or if the folding took place during deposition, in which case the change in dip would be more gradual. Observations at the outcrop indicate that the latter is probably the case.

To the writer's knowledge there is no other place in the Mid-Continent Field, where the sub-surface structure has been worked out in as much detail as has been done in the Cushing Field. Indications of similar conditions from different places in Oklahoma and Kansas are so numerous however, that the mode of folding as demonstrated for the Cushing Field can be considered the rule and not the exception. In his first reports on Oklahoma, in 1911, the writer has contended that the

[1]Frank Buttram: The Cushing Oil and Gas Field, Oklahoma, Okla. G. S. Bull. 18, 1914.

[2]Carl H. Beal: Geologic structure in the Cushing Oil and Gas Field, Oklahoma and its relation to the oil, gas and water, U. S. Geol. Survey Bull. 658, 1917.

subsurface structure was probably more pronounced than the surface structure for the reason that the folds shown at the surface are really too slight to be as regular and persistent as they are found in many places.

The importance of these unconformities need not be emphasized and it would be highly desirable to trace them to the outcrop, where they could be studied more carefully. The writer has been fortunate enough to do this in at least two instances.

Unconformity between Checkerboard limestone and Lost City limestone.

In doing some work in T. 19 N. R. 11 E. it was found that the lower formations are level from the dry hole in the southeast corner of Sec. 29 to the gas well in the northwest corner of the southwest quarter of the southwest quarter of Sec 20, while the surface rocks dip in that direction about one hundred feet to the mile. The surface observations were made on the sandstone ledges, which cap the bench west of Anderson Creek and are stratigraphically at least 200 feet above the Lost City limestone. The well records show that this limestone dips the same as the surface rocks, while the Checkerboard limestone and the lower formations show a different structure.

At the outcrop the interval between the Checkerboard limestone and the Lost City limestone was also studied and shows the following features:

Just northeast of Red Fork the Checkerboard limestone is exposed on the St. Louis and San Francisco railroad. The hills to the west are capped by a sandstone, which underlies the Lost City limestone. This sandstone bench and the limestone above can be traced to the southwest along the hills west of the St. Louis and San Francisco railroad to Sapulpa and hence along Polecat Creek, Euchee Creek and Browns Creek to Little Deep Fork Creek. Limestone exposures west of Okfuskee and northwest of Morse, which are conglomeratic in places, evidently belong to the Lost City horizon.

The outcrop of the Checkerboard limestone extends from Red Fork in a southerly direction to the Twin Mounds south of Glen Pool, where a fault throws it considerably to the east, then by way of Mounds along Checkerboard Creek to Deep Fork Canadian River, where it can be seen in Sec. 17, T. 14 N., R. 11 E.

Further excellent exposures which are considered to represent the Checkerboard limestone are found along Nuyaka Creek. In Sec. 17, T. 12 N., R. 10 E. there is a very sandy limestone and this horizon is represented in the railroad cut just north of Okemah by a calcareous sandstone full of fossils. This sandstone has been followed to the southwest and while it has not been mapped carefully all the way through it evidently correlates with a sandstone bench around Wewoka, the second one of the Seminole conglomerates above the Holdenville shales.

This divergence of the outcrops of the Lost City limestone and underlying sandstone on one side and the Checkerboard limestone on the other side indicates an increase in thickness of the intervening strata from Red Fork to the south. This is not only a thickening of the shale which is present north of Red Fork, but other members, which are entirely missing further north make their appearance. Between Red Fork and New Taneha a sandstone ledge sets in which rapidly increases in thickness and caps the hills between Sapulpa and Kiefer. This sandstone also caps the Twin Mounds and forms the bluff from Kiefer to Mounds and from there to the southwest to the vicinity of Morse and to the hills northwest of Okemah and southwest of Wewoka, evidently forming the third bench of the Seminole conglomerate. These ledges have been traced on the ground, but the main features can be seen on the topographic map, particularly on the more accurate Hominy and Kiefer sheets. There is also a limestone which appears under this sandstone bench and can be seen at the Twin Mounds south of Glenpool and around Tiger Creek west of Rocky Hill School. Evidently belonging to this horizon is a limestone exposure in the west part of Sec. 2, T. 13 N. R. 10 E., but it will take additional work to decide if the above mentioned limestone in Sec. 17, T. 12 N., R. 10 E., corresponds with this upper ledge or with the Checkerboard limestone.. A strong increase of thickness of the shale interval between the two limestones is in evidence between the Twin Mounds, where the Checkerboard is at the base of the northwest Mound, while the upper limestone occurs about half way up the slope and the territory around Rocky Hill School, where the exposures are about two miles apart, the Checkerboard limestone

on a creek in the prairie and the other limestone in the hills at least 200 feet above the plain. A rough estimate gives an increase of the shale interval between these two points of 200 feet in a distance of less than 12 miles.

From the stratigraphic sections accompanying this paper it can be seen that the interval between the Checkerboard and Lost City limestones increases from less than 300 feet (287 feet equals 87.5 meters) near Red Fork to over 400 feet (422 feet equals 128.5 meters) near Nuyaka Mission. At this latter place the thickness is considered somewhat less than in the vicinity of the Rocky Hill School.

This unconformity between the Lost City limestone and the Checkerboard has not been traced with absolute certainty to the Cushing Field. It either represents the one found above the Layton sand or the one below, or eventually both, as the Layton sand may be correlated with the sandstone appearing south of Red Fork and thickening to the south.

Other similar instances of series of strata, which thicken to the south with new members coming in are not uncommon in Oklahoma, but none have been studied closely at the surface and also proven by well records.

One instance of considerable thickening might be mentioned here. Along Spaniard Creek southeast of Muskogee, especially near its mouth there are several thin sandstone ledges in the Winslow formation, which thicken to the southeast towards McLain and rapidly diverge, thus proving a considerable increase in thickness of the intervening shales. Arnold Heim mentions in a report on this neighborhood, that the interval between the sandstone at McLain and the one forming the next higher bench to the southwest doubles its thickness in a southeasterly direction in a distance of six miles.

Unconformity in the Boggy Formation and Main Folding Period in Oklahoma.

Another unconformity in Oklahoma is closely connected with the main period of folding in this country. The only region of Oklahoma which was intensely folded is the region of the Ouachita, Arbuckle and Wichita Mountains. As far as we know this is a continuous mountain range extending eastward into

Arkansas and only separated by regions covered with formations younger than the folding of the mountains.

Quite a number of publications are available on the territory of these mountains, but they fail to give a comprehensive outline of the principal structural features. From the main literature and a few personal observations the writer got the following view of the formation of these mountains.

They are folded into a number of sharp anticlines, some of which have been folded so strongly as to create overthrust faults. The strongest disturbance of this kind is along the north line of the Ouachita Mountains and is known as the "Choctaw fault." This is evidently a big overthrust and the front part of the Ouachita Mountains has probably been shoved over for a considerable distance. The best indication of this is that formations of the same age in the Ouachita and in the Arbuckle Mountains have an entirely different character and must originally have been deposited at a considerable distance and later pushed to their present position by the mountain building forces.

The area to the north of the Ouachita Mountains was also affected by the folding and pushed in to anticlines, which are more gentle than the ones in the mountains proper, but still in places very pronounced, a few even with overthrust faults. The trends of these anticlines vary from east and west to the northeast and southwest. They are shown on maps of the Oklahoma survey[1], partly compiled from other publications and partly from the survey's insufficient field work.

The time of this mountain folding has not yet been determined accurately. Exposures in the Wichita Mountains localize the folding somewhere between Ordovician and middle Permian, while the Ouachita Mountains give it as somewhere between Silurian and Cretaceous unless the Jackfork sandstone belongs in the Carboniferous as some authors contend. The Arbuckle Mountains furnish somewhat better information. On the south side of the mountains proper in the vicinity of Ardmore and extending southward nearly to Marietta, where they are covered by Cretaceous, the strata show steep dips and are evidently sharp-

[1]L. C. Snider: Geology of east central Oklahoma, Okla. Geol. Survey Bull. 17, 1914.

ly folded. They are called the Glenn formation and considered lower Pennsylvanian, but neither their stratigraphy nor their structure has ever been properly studied. The Tishomingo folio shows the Franks conglomerate near Buckhorn deposited level on the folded and truncated older formations. This conglomerate is of Pennsylvanian age and has provisionally been correlated with the Wapanucka limestone[1]. East of Mill Creek the Franks conglomerate is strongly folded, same as the Wapanucka limestone in the vicinity of the Limestone Ridge. Unfortunately the author has never had a chance to trace the Franks conglomerate, but the above mentioned facts allow only two explanations. Either the folded and the unfolded Franks conglomerate are of different ages or there are two different phases of folding, the first one forming the anticlines, the second one affecting the Franks conglomerate in places and forming the overthrusts and also the folds to the north of the Choctaw overthrust.

Additional information as to the time of the main folding in Oklahoma can be gained by studying the more gentle folds in the territory north of the Choctaw overthrust. In this area the lower and middle part of the Boggy formation was folded together with the older formations, while the overlying formations, that is the ones from the Thurman sandstone up, show only low dips, two degrees being a rare exception. Farther north these formations named on the Coalgate folio[2] have not been distinguished and it is thought that some of the sandstone beds either pinch out or turn into shale going north. The heavy sandstones which cap the Council Hill and which may represent the Thurman sandstone thin so abruptly to the north that no bench can be seen and the one beginning near Haskell at about the same horizon is much less pronounced. The first formation above the unconformity, which has been named in the northern area and traced at least approximately, is the Ft. Scott. It has been correlated with the Calvin sandstone of the southern section. The

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[1]B. Franklin Wallis: The Geology and economic value of the Wapanucka limestone of Oklahoma, Okla. Geol. Survey Bul. 23, 1915.

[2]Joseph A. Taff: Coalgate Folio, U. S. Geol. Survey No. 74, 1901.

base of the Ft. Scott is probably about the same horizon as the base of the Calvin, but the top of the Ft. Scott will have to be looked for in the Wewoka formation[1]. The time of folding and with it the unconformity can be said to be near the top of the Boggy formation and at any rate considerably below the Ft. Scott.

The pronounced east and west folds can be found not only near Checotah and Muskogee but to the west as far as the vicinity of Haskell. No angular unconformity can be seen, which may be on account of these shaly members not being well exposed. The nearest to it is the observation, that the surface at the town of Council Hill indicates a dip slope to the south while just a little west of it in the Council Hill the strata dip perceptibly to the north. The folding is thought to have taken place during deposition and this is the reason why no angular unconformity can be seen. In the territory of the Boggy formation between Haskell and Council Hill the strike is east and west with the general dip to the south and in the higher strata it is north and south or northeast and southwest with a normal dip to the west. Even where the exposures are insufficient to figure out the structure strong dips and local faults are common in the Boggy shale, while these disturbances are practically missing in the higher strata.

This unconformity between the lower Boggy and the Thurman sandstone can plainly be seen in the well logs in the vicinity of Okmulgee (see well records). The first horizon which can be traced in the well records above the unconformity is the Henryetta coal and the first one below is the "Salt sand." The interval between these two horizons is subject to considerable change, generally an increase in thickness to the south, while the strata from the coal up conform with the formations at the surface.

As the main oil and gas sands of this territory are below the Salt sand, the structure of the producing horizons is somewhat different from the surface structure. This may be illustrated by the following instances:

[1]Edward Bloesch: North-South Correlation of the Pennsylvanian of Oklahoma, Bull. of the Southwestern Association of Petroleum Geologists. Vol. 1, 1917.

Fath[1] has shown that in the pool south of Beggs the structure of the oil sand is quite different from the surface structure.

In the oil pool in sections 25 and 36 T. 14 N. R. 11 E., the strata at the surface dip to the west at the rate of at least 50 feet to the mile. Only about half a mile east of the pool the rate of dip decreases. Data gained from the well logs prove that the strata from the Salt sand down show enough east dip to account for the accumulation of the oil. The pool now being developed in Sec. 31, T. 14 N., R. 12 E., and Sec. 6, T. 13 N., R. 12 E., shows similar conditions.

Not very far from this place a considerable south dip of the deep strata has been observed. In and near Sec. 13, T. 13, R. 11 E., the dip of the surface formations is a little north of west at the rate of about 150 feet to the mile and in the lower strata the dip is west of south at the rate of 80 feet to the mile or in other words in a north and south direction the surface formations dip slightly to the north while at the depth of the producing horizons the dip would be 80 feet per mile to the south.

As proven by the investigations in the Cushing Field (Beal loc. cit.) this unconformity can be traced a long way to the northwest and should be looked for between a horizon marked by the Fort Scott or Oswego lime of the drillers or the Wheeler sand of the Cushing Field, which is considered the same horizon and a sand group represented by the Bartlesville sand of Cushing, the Glenn sand of the Glenn pool and the Salt sand of the Okmulgee district, which sands are, if not identical, not so very far apart.

The author has tried to trace the Salt sand of Okmulgee to its outcrop. This is somewhat difficult on account of the well records being very unreliable in their upper part close to the surface. The Salt sand and with it the Glenn sand of the Glenn pool most likely crop out in the uppermost part of the Winslow formation as it is mapped on the Muskogee folio[2] west of Muskogee. This top sandstone of the Winslow west of Muskogee is evidently the same as the one mapped as Boggy in the Rattlesnake Moun-

[1]A. E. Fath: A structural reconnaisance in the vicinity of Beggs, Okla. Geol. Survey Bull 19, part 2, 1917.

[2]Joseph A. Taff: Muskogee Folio, U. S. Geol. Survey No. 132, 1905

tains, the mapping of this part of the Muskogee folio being inaccurate.

The east and west system of folding does not play out entirely west of the Haskell-Council Hill line, but can be found in slight west plunging anticlines, structural noses and crossfolds. The direction of these folds varies from east-west to southeast-northwest and while they are generally not pronounced they are quite frequently found. They have hardly been mentioned in the literature, except in the Osage, (U. S. Geol. Survey Bull. 686 and the Glenn Pool[1] bulletins) but extend, proven partly by observations of the writer and partly by the line up of oil and gas production, as far north as Kansas (see structure contours of the Independence folio[2]) and as far west as Ralston. Farther west they seem to be absent either because this folding took place before Permian time or on account of too great a distance from the mountains.

There is evidently some connection between this system of folding and the folding of the Ouachita-Arbuckle Mountains. The evidence at hand indicates that the folding which took place in Boggy time extended farther west and north, than can be seen at the surface and that later, after deposition of the upper Pennsylvania, a new but slight folding occurred at the old places of weakness. Just how strong this old folding was can not be figured out from our present information. In the Cushing Field the main difference in the structure of the Wheeler and Bartlesville sands is the fact that in the Bartlesville the crossfolds are much more accentuated.

That the principal folding period in Boggy time was not the last mountain forming process in the main range of Oklahoma is indicated by the deposition of the Seminole conglomerate, a series of conglomeratic sandstones interstratified with shale and occasional limestone, which comprise the whole interval between the Holdenville shale and the Elgin sandstone in the vicinity of Paden.

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[1]Carl D. Smith: The Glenn Oil and Gas Pool and Vicinity, Oklahoma, U. S. Geol. Survey Bull. 541, B. 1913.

[2]F. C. Schrader: Independence Folio, U. S. Geol. Survey No. 159, 1908.

Right in line with the Wichita mountains the author has observed a flexure-like disturbance in sections 34 and 35 T. 7 N. R. 24 W., where the Greer formation dips at least 70 degrees to the north. In section 20 of the same township there is a south dip of at least 30 degrees. The intervening strip of land has either sunk down or the territory on both sides has been uplifted indicating that the line of folding of the Wichita Mountains was still a line of weakness in upper Permian time.

Finally the Trinity sand shows a stronger south dip along the Missouri, Kansas and Texas railroad just south of Atoka than farther on south. This indicates a slight uplift of the mountains during or after the Cretaceous.

Thickening of the Pennsylvanian in Oklahoma.

The thickening of the Pennsylvanian in Oklahoma from north to south is very considerable. The thickness of the part below the Fort Scott for instance is given in the Independence Folio as 450 feet, while in the Coalgate Folio the interval between the Calvin sandstone and the Mississippian is said to be about 9000 feet. (Unfortunately the thickness varies not only in different parts of the area covered by the folio but also between the description and the columnar section.) The lower part of the Pennsylvanian section of the Coalgate folio, namely the Atoka formation, thickens also in an easterly direction from about 3,000 feet to 7,000 feet in the vicinity of Poteau[1].

This thickening to the south is due to the location of a geosyncline at the present place of the Ouachita—Arbuckle Mountains. It can be divided into different phases:

The *Atoka Formation* is missing entirely in northern Oklahoma either on account of non-deposition or erosion or probably a combination of both.

The *Winslow* thickens considerably to the south as has particularly been noticed in the vicinity of McLain. It thickens from about 1000 feet near Muskogee to 3000 feet near Coalgate forming there the Hartshorne sandstone, McAlester shale and Sa-

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[1]Carl D. Smith: Structure of the Fort Smith, Poteau Gas Field, Arkansas and Oklahoma U. S. Geol. Survey Bull. 541 B. 1913.

vanna sandstone. In the south part of the Muskogee quadrangle the Winslow has a thickness of at least 1500 feet instead of 1000 feet as given by Taff.

During *Boggy* time the lowering of the Geosyncline reached a limit and, the earth crust being weakened, folding set in, which produced the anticlines and overthrusts not only in the Ouachita and Arbuckle Mountains, but also in the territory to the north. During this process the mountain area was elevated above sea level and partly eroded, while the more gentle folding to the north took place during deposition and, the south part of the area still sinking, thicker deposits were laid down near the mountains than farther north. In this way the thickness of the Boggy formation got to be at least twice as great around Coalgate as it is near the Arkansas River.

After the folding of the Boggy started, evidently thicker deposits were laid down in the synclines than along the anticlines. Even after the main part of the folding process was over, that is during deposition of the *Tulsa* and *Sapulpa* group, the thickening to the south was not regular. A number of stratigraphic sections made between Deep Fork Canadian River and Canadian River indicate the rule that all the formations thicken at a certain place, while they all thin again together, the increase in thickness from north to south amounting to more than the decrease. The sections show a maximum of thickness just north of Weleetka, then a decrease to the neighborhood of Wetumka and a considerable increase to the latitude of Holdenville.

Appearance of new members from north to south is not uncommon. The one in the interval between Checkerboard and Lost City limestones south of Red Fork has been described. Other instances which may be mentioned are the appearance of a sandstone in the lower part of the Wetumka shale in the vicinity of Wetumka and of new sandstone ledges in the Calvin south of North Fork Canadian River. Near Deep Fork Canadian River sandstones appear between the limestone west of Schulter and the Henryetta coal, which are missing farther north between the lower Fort Scott limestone, which is considered the same as the one near Schulter, and the coal east of Broken

Arrow. It is not quite sure, however, that these two coals represent exactly the same horizon. It is possible that the Henryetta coal is stratigraphically lower than the coal of Broken Arrow. The sandstone member of the Fort Scott increases in thickness in crossing the Arkansas River and forms the Concharty Mountains.

A comparison of the section given by Ohern[1] north of the Arkansas River with one published in this paper from Schulter to Nuyaka Mission gives an increase of the interval between the lower Fort Scott Limestone and the Checkerboard or in other words of the Tulsa group, from about 400 feet to nearly 1,200 feet. From U. S. Geological Survey Bulletin No. 686, the interval between the Hogshooter limestone and the Pawhuska formation in the Osage has been estimated at about 1400 feet and Green[2] gives it as about 1300 feet. The interval between the Lost City limestone, the equivalent of the Hogshooter, and the Pawhuska in the section Nuyaka Mission—Depew is about 1200 feet, indicating that the differences in thickness of the series above the Hogshooter-Lost City horizon are only local, but not general. (The difference of 100 or 200 feet is more likely due to inaccuracy of the sections than to a decrease in thickness to the south). For the whole Sapulpa group we find a thickness of 1700 and 1600 feet respectively in these two sections, that is, practically no change in thickness.

The upper part of the Pennsylvanian, the *Ralston* group also does not thicken much to the south. Evidently the geosyncline near the mountains ceased to subside sometime during the Sapulpa group. A change in the conditions of sedimentation is also indicated by the appearance of a considerable amount of Red Beds.

Unconformities near the Pennsylvanian-Mississippian Contact.

The lowest Pennsylvanian in northeastern Oklahoma, the

[1]D. W. Ohern: The stratigraphy of the Older Pennsylvanian Rocks of Northeastern Oklahoma. The State University of Oklahoma, Research Bulletin No. 4, 1910.

[2]F. C. Green: A Contribution to the Geology of Eastern Osage County. Bull. of the American Association of Petroleum Geologists, Vol. 2, 1918.

Marrow formation is described as unconformable with the Winslow above and the Pitkin below in the Muskogee folio (Taff loc. cit.) while the different formations of the Mississippian seem to be conformable. In the Tahlequah folio[1] adjoining on the east unconformities are supposed to occur between Winslow and Morrow, between Morrow and Pitkin and between Fayetteville and Boone. In the section of the Winslow folio[2] the only unconformity mentioned is between Fayetteville and Boone and sections across the line in Arkansas are different again. The unconformities evidently are not very pronounced and vary somewhat but the difference in adjoining areas is probably due to the fact that these unconformities have not been studied close enough.

According to Snider[3], who recently studied the position, the main unconformity is between Boone and Chester with another one between Pitkin and Morrow and a minor uconformity in the Morrow. The different members of the Chester and Morrow cut out to the north in an irregular manner thus forming locally an unconformable contact between the different formations until finally at the Kansas line the Cherokee rests directly on an erosional surface of Boone.

The unconformities are evidently not due to folding or a perceptible amount of tilting but to elevation above sea level with lack of deposition and local erosion.

Away from the outcrop where these unconformities can only be studied from well logs the conditions are quite different than they are at the surface, in fact they are more similar to the sections published near the Arkansas line than in the Muskogee folio.

The well records generally show a series of limestones which in the Glenn Pool section have been considered to represent the

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[1]J. A. Taff: Tahlequah Folio, U. S. Geol. Survey No. 122, 1905.

[2]A. H. Purdue: Winslow Folio, U. S. Geol. Survey No. 154, 1907.

[3]L. C. Snider: Geology of a portion of Northeastern Oklahoma, Okla. Geol. Survey Bull. 24, Part 1, 1915.

Morrow and Pitkin (Carl D. Smith loc. cit.). This group of limestones shows up in all the logs of deep wells in the vicinity of Tulsa and is underlaid by a shale sandstone group which produces oil (Mounds sand). This represents evidently the Fayetteville of the surface section, possibly also the Batesville sandstone known in Arkansas. To the north the formations between the Winslow (Cherokee) and the Boone get thinner and evidently pinch out as in the Kansas section the Cherokee rests directly on the Boone.

The "Structure Map of Eastern Kansas"[1] which is a contour map on top of the Mississippian shows a level place between Montgomery County and Western Chautauqua County. This is evidently the place where the Pitkin sets in, the contours to the east being drawn on the Boone, the ones to the west on the Pitkin.

In the territory between Catoosa, Broken Arrow and Wagoner the well records generally show a solid body of limestone about two hundred feet thick. Above this one there are other thin limestone ledges and below there is some shale and sandstone and finally some more limestone of a flinty nature (See well record). A provisional correlation with the surface section would indicate that the upper limestone ledges would correspond with the Morrow, the two hundred feet of limestone with the Pitkin, the shales and sandstones with the Fayetteville and the lower cherty limestone with the Boone.

The heavy limestone can be traced southward in the well records into the north part of T. 15 N., R. 15 E. It is still reported in sections 14 and 23 (see well record), but then suddenly disappears. Only thin ledges of limestone are present which may represent the Pitkin and they are at a lower level indicating an increase in thickness of the overlying formations.

From the Glenn Pool south the interval between the Glenn sand and the limestone group representing the Morrow and Pitkin increases rapidly. It is about three hundred feet in the Glenn

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[1]Raymond C. Moore and Winthrop P. Haynes: Oil and Gas Resources of Kansas, Kansas Geol. Survey Bull. 3, Plate 25, 1917.

Pool and seven hundred or eight hundred feet in T. 13 N., R. 12 E. (see well record). An accurate correlation of the well logs and detailed study of the unconformity are practically impossible as the well records are not accurate enough for this purpose. They prove an unconformity evidently on account of thickening of the portion just above the limestone or because new members appear. Below this first limestone all the well records which went deep enough show considerable more limestone but it is not possible to state at present if this is all part of the Pitkin or if the Boone appears. A correlation with the section of the Arbuckle Mountains is still more difficult.

Oil Sands in the Okmulgee District.

A short outline of the producing horizons in the Okmulgee territory, one of the most important producing districts of the state may not be out of place, particularly because they were pretty badly mixed up by their writers.

The first sand of considerable regularity is the salt sand which got its name from the fact that it is generally full of salt water. It is evidently the Glenn sand of the Glenn Pool region. It produces oil and gas in a few localities. This sand is reported as being 100, 150 or 200 feet thick but careful records would probably show that there are several sand members separated by shale.

The next sand about 300 feet below the salt sand is called the Booch sand. In T. 14 N. R. 14 E. where it has furnished most of the production, there are sometimes two generally thin Booch sands. West of Okmulgee the Booch is represented by a group of sands producing oil or gas in places, and containing water in others. A good many well records gives the Booch west of Okmulgee as a solid sand of 100 or 150 feet thickness, but this is certainly not accurate.

The next group of sands about 300 feet below the Booch contains the main producing sands of the Morris field, Pine Pool, Bald Hill Field, Preston Pool, Beggs Pool, Tiger Flats, Salt Creek Pool and the recent development from there northward to Beggs.

This group of sands and the Booch belong to the Winslow formation, while the salt sand is evidently the lower Boggy

sandstone. No unconformities have been noticed in this interval.

The lower sands are harder to correlate, partly because less well records are available and partly on account of the unconformities. A very important deep sand has been located in Sec. 9, T. 13 N., R. 12 E. at 2700 feet and just recently an oil well has been completed in section 26 of the same township in the 2900 foot sand (see well record).

Production in the Mississippian.

The oil production of Oklahoma has until recently been considered as belonging entirely to the Pennsylvanian. Considerable production in different parts of the territory is below the Pitkin and consequently in the Mississippian, particularly the Mounds sand and several deep sands of the Okmulgee district. The deepest oil producing horizon in the main Oklahoma field is probably the Boone. At least some of the production of northeastern Osage County seems to be in the Boone. The writer has seen drillings of a producing horizon northwest of Bartlesville which closely resemble the chert of the Boone. From the Miami and Joplin lead and zinc district occurrences of heavy residual oil are known at the same horizon. It is most likely that this oil accumulated in the cavities caused by solution of the Boone when it was at the surface. From this it might be expected that in places where the Boone did not form a land surface, that is, to the west and south, it would be less apt to contain oil.

Correlation of Well Records.

If there were no unconformities, changes in thickness and the like, correlation of well logs would be very simple. All needed would be a stratigraphic section all the way across the state and then the stratigraphic position of the mouths of the wells could be tied in by following and mapping a key horizon. On account of the unconformities this method allows only to correlate the top part of logs down to the next unconformity. Where an unconformity consists in a gradual change in thickness it is necessary to have records of wells which are not too far apart to affect an accurate correlation. Where unconformities are pronounced and localized to a certain horizon it is necessary

to correlate the different parts of the logs between the separate unconformities. For this purpose it is very important to know the place and nature of the unconformity. The unconformities cannot very well be studied from the well records as most of them are not accurate enough but ought to be studied at the surface. After an unconformity has been located exactly and its nature figured out, that is if it is an angular unconformity or a gradual change during a certain interval then it is possible even if the well records are not quite accurate to recognize the unconformity in the records and correlate them properly.

Practical Importance of the Unconformities.

It is evident that these unconformities must be considered carefully in making deductions as to the accumulation of oil and gas. Where well records are available the subsurface structure should be figured out from these and eventually not only the structure of one horizon but of several horizons separated by unconformities. Even where well records are available the surface structure should be studied as it will give valuable hints on how to interpret the well records. Faults in particular cannot easily be detected from well records and it is very helpful to locate them at the surface. As far as surface observations are concerned the geologist will know what part of the structure is certain and what part is not. In figuring from well records one does not know how accurate the available information is. On the other hand it is not always necessary to work out the surface structure in a very detailed way where prominent unconformities are known to occur above the producing horizon.

Where no well records or only an insufficient number are available the subsurface structure can be deducted in a general way from the surface structure. The reversals are probably stronger with increasing depth and therefore small anticlines and terraces have a better chance to be productive than could be expected from the surface structure. The author has stated[1] that, figuring from surface observations, only about one fourth of

[1]Edward Bloesch: Value of Oil Geology in the Mid-Continent Field, Bull. of the American Association of Petroleum Geologists, Vol. 2, 1918.

the pools in the Mid-Continent Field are located on terraces but that a certain number of these terraces might be anticlines at the depths of the producing sands or that in some instances lensing of the sand may accumulate oil at the place of the terrace. Considering the unconformities it is more than likely that a large number of terraces will prove to be anticlines at the depths of the producing horizons. Even on slight structure test wells ought to be drilled to the deep sands as with increasing depth the structure may become more favorable.

Some pronounced anticlines may not show at the surface at all but this case is not thought to be a common occurrence. To what extent the axes of anticlines and synclines may change their position between the surface and the deep sands cannot be stated from present information but the deviation if present at all is not thought to amount to a great deal.

In and below the Boggy formation, or in other words in the Bartlesville and lower sands, folding in eastwest or southeast northwest direction can particularly be expected to be more strongly developed than at the surface.

The main change between surface and subsurface structure will be an increase of the south dips and a decrease of the north dips. It has been shown, however, that this increase in thickness to the south is by no means regular and in order to deduct the subsurface structure from the surface structure the geologist ought to be well acquainted with the nature of the unconformities in that particular part of the field.

The study of unconformities and the figuring out of subsurface structure in Oklahoma is greatly handicapped by the fact that the big majority of the well records is not accurate or not detailed enough and the importance of keeping accurate and detailed logs of all the wells cannot be emphasized too much. The knowledge that can be gained from such well records is not only of great scientific value but will easily pay the operator for the extra trouble necessary to procure this information.

Stratigraphic Sections and Well Records.

The following stratigraphic sections do not claim to be very accurate. The shales in particular can contain other formations

which have not been seen exposed. The identifications of the formations in the well records are partly subject to revision.

Section Near Red Fork.

Shale	
Limestone, Lost City	3 Meters
Shale,	3
Sandstone	2
Shale	1
Sandstone	1
Shale	1
Sandstone	1
Shale	1
Shale	2
Sandstone	1
Shale	2.5
Sandstone	2
Shale	28
Sandstone	2
Shale	39
Black Slate	2
Limestone, Checker-board	1
Shale	

Section from Schulter to Depew.

	(Approximately)
Limestone, Base of Pawhuska Formation	
Shale and Sandstone poorly exposed	250 Meters
Limestone, Avant?	0.5
Shale, Sandstone near top	16.5
Sandstone	1
Shale, sandstone near bottom	19
Limestone, Dewey?	0.5
Shale	11.5
Sandstone	1
Shale	9
Sandstone	2
Shale	2

Sandstone	2 Meters
Shale, with Lime concretions	28
Limestone, Lost City	0.5
Shale	1.5
Sandstone	1.5
Shale	8.5
Sandstone	2
Shale, with Sandstone	57
Sandstone	2
Shale	56
Limestone, Checker-board	1
Shale	14
Sandstone	2
Shale	68
Sandstone	0.5
Shale	7.5
Sandstone	1
Shale	9
Sandstone	1
Shale	5
Sandstone	0.5
Shale	3
Sandstone	0.5
Shale	3
Sandstone	2
Shale	1
Sandstone	2
Shale	1
Sandstone	2
Shale, Sandstones in lower part	72
Sandstone	2
Shale	65
Sandstone	1
Shale	64
Sandstone	2
Shale and Sandstone	7
Sandstone	2
Shale	13

Limestone, Lower Fort Scott	0.3 Meters
Shale	46
Sandstone	1
Shale	22
Sandstone	2
Shale	24
Coal, Henryetta,	0.5
Shale	

Record of Test of the Betty B. Oil & Gas Company in the North-west corner of Sec. 3, T. 17 N., R. 15 E.
(Courtesy of Mr. W. I. Goble.)

Surface	43 ft.	0	to	43
Sand, soft, water	20 ft.	43	to	63
Shale, black, soft	97 ft.	63	to	160
Shale, brown	94 ft.	160	to	254
Slate, White, Soft	66 ft.	254	to	320
Shale, Brown, Soft	42 ft.	320	to	362
Lime, White, Hard	29 ft.	362	to	391
Shale, Brown, Soft,	89 ft.	391	to	480
Shale, Black, Soft	35 ft.	480	to	515
Shale, White, Soft	14 ft.	515	to	529
Lime, Gray, Soft	6 ft.	529	to	535
Shale, Brown, Soft	75 ft.	535	to	610
Slate, Black, Soft,	65 ft.	610	to	675
Shale, Brown, Soft	95 ft.	675	to	760
Slate, Gray, Soft	102 ft.	760	to	862
Lime, Gray, Soft	4 ft.	862	to	866
Shale, Brown, Shelly	24 ft.	866	to	890
Lime, Gray, Hard	6 ft.	890	to	896
Shale, Brown, Soft	49 ft.	896	to	945
Lime, Gray, Hard	20 ft.	945	to	965
Not recorded				987
Slate, Black, Soft	15 ft.	987	to	1002
Shale, Black, Soft	63 ft.	1002	to	1065
Lime, Gray, Hard	5 ft.	1065	to	1070
Shale, White, Soft	8 ft.	1070	to	1078
Lime, Gray, Very Hard	12 ft.	1078	to	1090
Slate, Black, Soft	14 ft.	1090	to	1104

Sand, Hard, (Gas at 1109)		20 ft.	1104 to 1124
Shale, White,		5 ft.	1124 to 1129
Shale, Black		15 ft.	1129 to 1144
Lime, Gray, Hard	Morrow	16 ft.	1144 to 1160
Shale, Light, Soft	Morrow	5 ft.	1160 to 1165
Lime, Light, Hard	Morrow	35 ft.	1165 to 1200
Shale, Gray, Soft	Morrow	5 ft.	1200 to 1205
Lime, Light, Hard	Morrow	22 ft.	1205 to 1227
Shale, Black, Soft		98 ft.	1127 to 1325
Shale, Light, Soft		7 ft.	1325 to 1332
Lime, White, Hard	Pitkin	21 ft.	1332 to 1353
Shale, Brown, Soft	Pitkin	12 ft.	1353 to 1365
Lime, Light, Hard	Pitkin	118 ft.	1365 to 1483
Slate, Dark, Soft	Pitkin	14 ft.	1483 to 1497
Lime, Brown, Hard, Flinty	Pitkin	25 ft.	1497 to 1522
Shale, Blue, Firm		8 ft.	1522 to 1530
Lime, Light, Hard		4 ft.	1530 to 1534
Slate, Dark	Fayetteville	70 ft.	1534 to 1604
Sand, Green	Fayetteville	76 ft.	1604 to 1680
Sand, Light	Fayetteville	84 ft.	1680 to 1764
Lime and Sand	Fayetteville	6 ft.	1764 to 1770
Sand, White, Loose	Fayetteville	3 ft.	1770 to 1773
Sand, White, Hard	Fayetteville	2 ft.	1773 to 1775
Sand, White, Loose	Fayetteville	4 ft.	1775 to 1779
Sand, White, Loose Water	Fayetteville	11 ft	1779 to 1790
Mississippi Lime, Gray, Hard (Boone)		3 ft.	1790 to 1793

Record of Test in Northwest Corner of Southwest Quarter of Sec. 23, T. 15 N., R. 15 E.

Soil	15 ft.	0 to 15
Sand	3 ft.	15 to 18
Shale	226 ft.	18 to 244
Sand (Show of oil and water)	44 ft.	244 to 288
Shale	52 ft.	288 to 340
Sand	10 ft.	340 to 350
Shale	32 ft.	350 to 382
Sand	13 ft.	382 to 405

Shale	115 ft.	405	to	520
Lime	6 ft.	520	to	526
Shale	6 ft.	526	to	532
Lime	16 ft	532	to	548
Shale	34 ft.	548	to	582
Sand, Salt Sand	46 ft.	582	to	628
Shale	221 ft.	628	to	849
Sand	15 ft.	849	to	864
Sandy Shale	46 ft.	864	to	910
Lime	19 ft.	910	to	929
Shale	10 ft.	929	to	939
Sand, Shells	9 ft.	939	to	948
Sand	17 ft.	948	to	965
Shale	15 ft.	965	to	980
Sand	17 ft.	980	to	997
Shale	38 ft.	997	to	1035
Lime	17 ft.	1035	to	1052
Sand (Gas) Booch	63 ft.	1052	to	1115
Slate	40 ft.	1115	to	1155
Sand	8 ft.	1155	to	1163
Lime	9 ft.	1163	to	1172
Sand	8 ft.	1172	to	1180
Slate	172 ft.	1180	to	1352
Lime, Pitkin	158 ft.	1352	to	1510
Sand	16 ft.	1510	to	1526
Shale	114 ft.	1526	to	1640
Sand	8 ft.	1640	to	1648
Shale	22 ft.	1648	to	1670
Sand		1670		

Record of Well in Northeast Corner of the Northwest Quarter of the Northwest Quarter of Sec. 26, T. 13 N., R. 12 E.

Sand	42 ft.	0	to	42
Slate	38 ft.	42	to	80
Sand	45 ft.	80	to	125
Slate	70 ft.	125	to	195
Sand, water	35 ft.	195	to	230
Slate and Shale	360 ft.	230	to	590
Sand (Little Oil)	10 ft	500	to	600

Shale		490 ft.	600 to 1090
Lime Shell		4 ft.	1090 to 1094
Shale		21 ft.	1094 to 1115
Sand		20 ft.	1115 to 1135
Shale and Slate		120 ft.	1135 to 1255
Sand (Water at 1435)	Salt Sand	205 ft.	1255 to 1460
Shale		65 ft.	1460 to 1525
Lime Shell		3 ft.	1525 to 1528
Shale		72 ft.	1528 to 1600
Sand (Oil Show)	Booch	4 ft.	1600 to 1604
Shale	Booch	88 ft.	1604 to 1692
Booch Sand	Booch	12 ft.	1692 to 1704
Slate		86 ft.	1704 to 1790
Lime		4 ft.	1790 to 1794
Shale		86 ft.	1794 to 1880
Lime		18 ft.	1880 to 1898
Shale		32 ft.	1898 to 1930
Lime		10 ft.	1930 to 1940
Shale		80 ft.	1940 to 2020
Sand		25 ft.	2020 to 2045
Lime		5 ft.	2045 to 2050
Shale		68 ft	2050 to 2118
Sand (Gas)		6 ft.	2118 to 2124
Sand (Water at 2144)		38 ft.	2124 to 2162
Lime		6 ft.	2162 to 2168
Slate		30 ft	2168 to 2198
Lime	Morrow ?	89 ft.	2198 to 2287
Sand		23 ft.	2287 to 2310
Lime,	Pitkin	75 ft.	2310 to 2385
Shale		30 ft.	2385 to 2415
Lime		20 ft.	2415 to 2435
Shale		200 ft.	2435 to 2635
Lime, Pitkin ?		195 ft.	2635 to 2830
Shale		35 ft.	2830 to 2865
Black Lime		25 ft.	2865 to 2890
White Lime		25 ft.	2890 to 2915
Sand (Oil pay at 2940)		27 ft.	2915 to 2942
Total Depth			2945

Record of Well in the Southeast Quarter of the Northeast Quarter of Sec. 30, T. 12 N., R. 13 E. (Courtesy of Mr. W. B. Pine)

Yellow Mud		20	ft.	0	to	20
Slate		97	ft.	20	to	117
Coal Henryetta		3	ft.	117	to	120
Slate		205	ft.	120	to	325
Sandy Shale		15	ft.	325	to	340
Sand Water		50	ft.	340	to	390
Slate		144	ft.	390	to	534
Lime		6	ft.	534	to	540
Sand		20	ft.	540	to	560
Slate		10	ft.	560	to	570
Sand, little gas		16	ft.	570	to	586
Slate		124	ft.	586	to	710
Sand, hole full of water		50	ft.	710	to	760
Slate		64	ft.	760	to	824
Sand, little gas		36	ft.	824	to	860
Slate		90	ft.	860	to	950
Sandy Shale		50	ft.	950	to	1000
Slate		60	ft.	1000	to	1060
Shale		54	ft.	1060	to	1114
Sand shell, gas		2	ft.	1114	to	1116
Slate		24	ft.	1116	to	1140
Sand, ten million cu. ft. of gas oil at 1195	Salt Sand	147	ft.	1140	to	1287
Slate		173	ft.	1287	to	1460
Shelly		40	ft.	1460	to	1500
Shale		80	ft.	1500	to	1580
Sand shell	Booch	3	ft.	1580	to	1583
Shelly	Booch	18	ft.	1583	to	1601
Sand, hole full of water	Booch	204	ft.	1601	to	1805

Record of Test in Northwest Corner of Southeast Quarter of Sec. 31, T. 12 N., R. 13 E. (Courtesy of Mr. W. B. Pine.)

Sandstone	Calvin	10	ft.	0	to	10
Yellow Mud		20	ft.	10	to	30
White Slate		70	ft.	30	to	100

Blue Mud	50	ft.	100	to	150
White Slate	103	ft.	150	to	253
Coal Henryetta	3	ft.	253	to	256
White Slate	70	ft.	256	to	326
Brown Shale	174	ft.	326	to	500
Sand	75	ft.	500	to	575
White Slate	95	ft.	575	to	670
Lime	8	ft.	670	to	678
White Slate	12	ft.	678	to	690
Sand	30	ft.	690	to	720
White Slate	30	ft.	720	to	750
Black Slate	50	ft.	750	to	800
Shelly	20	ft.	800	to	820
Sand, little gas, hole full of water	90	ft.	820	to	910
Black Slate	55	ft.	910	to	965
White Slate	25	ft.	965	to	990
Sandy Shale	40	ft.	990	to	1030
Brown Shale	115	ft.	1030	to	1145
Sandy Shale	35	ft.	1145	to	1180
Black Slate	25	ft.	1180	to	1205
Black Slate	104	ft.	1205	to	1309
Sand, One million cu. ft. of gas at 1329; oil at 1372; two bailers of water; oil at 1412, Salt sand	163	ft.	1309	to	1470
Brown Shale	130	ft.	1470	to	1600
Lime Shell	7	ft.	1600	to	1607
Brown Shale, Gritty	193	ft.	1607	to	1800
Sand, oil at 1819; 2 bailers of water at 1820	50	ft.	1800	to	1850
Black Slate	40	ft.	1850	to	1890
Sand, hole full of water at 1950 (Booch)	175	ft.	1890	to	2065
Black Slate	50	ft.	2065	to	2125
Shelly	20	ft.	2125	to	2145
Brown Shale	25	ft.	2145	to	2170
Lime Shell	12	ft.	2170	to	2182
Slate and Shells	63	ft.	2182	to	2255
Sand	40	ft.	2255	to	2295
Shelly	43	ft.	2295	to	2338
Sand	17	ft.	2338	to	2355

Brown Shale	45 ft. 2355 to 2400
Lime	28 ft. 2400 to 2428
Sand	9 ft. 2428 to 2437
Brown Shale	63 ft. 2437 to 2500
Shelly	38 ft. 2500 to 2538
Sand, oil at 2542	17 ft. 2538 to 2555
Brown Shale	30 ft. 2555 to 2585
Sandy Lime	22 ft. 2585 to 2607

THE RELATIONS OF STRATIGRAPHY AND PALEOGEOGRAPHY TO PETROLEUM GEOLOGY.

By Charles Schuchert, *New Haven, Conn.*

When one sees American geologists, and especially those interested in the exploitation of petroleum, annually gathering to talk over their results, it is a most hopeful sign that we may soon expect greater advances in our knowledge of underground stratigraphy and paleogeography. But when, on the other hand, one thinks of the million or so driven wells of the United States, of which probably not more than 3 to 4 per cent have published logs of such accurate scientific worth as to be useful to the stratigrapher, we see at once how many of the possibilities for enhancing geologic knowledge in this way have practically come to nothing. It is true that much knowledge has been gathered by the seeker for petroleum as to the many formations which have deposits of solid hydrocarbons, and as to what the geologic structures and natural reservoirs are that have led to the subsequent accumulation of these highly valuable but fleeting liquid and gaseous organic residues; and in these connections I have nothing other than praises to offer. But what should have been another good by-product—detailed stratigraphy and paleontology—has in general been wasted as shamefully as the gas in some gushers.

It is encouraging to observe that most far-seeing petroleum companies have now learned the importance of geology, and that the geologist can help in pointing out the probable places where this great wealth may be stored. But the field geologists and the oil companies have not yet realized what can be done for them by the generalizing stratigrapher, and especially the paleogeographer, who base their knowledge on the wider distribution of fossils in space and time, and of the ancient sea-ways. A thorough co-operation between the field geologist and the closet paleontologist can only be beneficial to the oil companies, and by a long look ahead the work could be done at no ultimate cost to the companies. It should not be taken amiss if I add here that we, the high priests of geology and paleontology, have a right to ask for help so that we may place our sciences

upon a still higher plane. Surely, the higher the plane of geologic endeavor, the more practical will be the possibilities of oil recoveries. The paleontologist has always been more than willing to give his knowledge to any one for the asking, and in some cases he has gone so far as to pay for his own time and publications. Clearly this hard-won knowledge should be sought for, and we are ready to believe that the large oil companies are willing to advance the knowledge of their own undertakings. Accordingly, the paleontologists will be found as willing to assist in filling the tanks of the pipe lines with the garnered petroleum as are the geologists and the engineers.

As a stratigrapher, let me, therefore, direct your attention more specifically to the imperfection of the stratigraphic sequence, the shallowness of the inland or epeiric seas, and the positions of the ancient shore-lines, all of which have a direct bearing on the presence and storage of the hydrocarbons in the stratified rocks.

Manual of Guide Fossils: What a boon it would be, not only to the petroleum geologist, but to all geologists who are trying to find a way through the maze of undeciphered stratigraphy, if we had a descriptive book, properly illustrated, dealing with the guide fossils to the many important formations. This knowledge to a large extent lies buried in our technical literature, so that but few stratigraphers are able to use it, scattered as it is in thousands of volumes. The stratigrapher of a few years' standing can not use the published record, even when it is accessible, for the pitfalls, the errors discovered by later authors, are so numerous as to lead the inexperienced into hopeless confusion. Nor can any one stratigrapher write such a book for the entire geological column, though a half dozen American paleontologists working in unison could do it well. But how can these half dozen "autocrats," unassisted financially, produce this desideratum, for, after all, paleontologists are mortals like geologists, and need three square meals each day and a soft couch at night on which to rest their troubled heads? And before such a book is completed, many a consultation and heated debate must be had. Then probably $2000 would be necessary to provide the desired illustrations. Having even progressed so far, I won-

der if any of our publishers would undertake on their own account to produce so expensive a volume, since it probably could not be put on the market for less than $10 per copy. But if such a book were on sale to-day, more copies of it could be sold in Kansas, Oklahoma and Texas than in the rest of the United States, such is the appreciation of stratigraphy in that region. Truly it would save many a futile effort, and especially in the Red Beds country, and a single deeply driven "fool-well" would more than pay for the entire cost of preparing it. Who will be the patron to make it possible to produce this guide for the seeker of the record that lies buried in the strata?

We must, however, warn our would-be patron that upon the publication of such a book no golden paradise would be laid bare by the paleontologist for the petroleum geologist to walk into and help himself to all of the largest nuggets, since it is well known that the oil and gas pools are conditioned by certain geologic structures superposed upon beds of black shales and porous sandstones. Nevertheless, through such a book, the path of the oil-seeking geologist would be strewn with roses rather than with the thorns of doubt.

Value of Fossils: Immediately the possibilities of an oil field are discovered, the stratigraphic and paleontological problems become local ones, for now it is the minutiae of the organisms and their changing environments that tell the local stratigrapher the probable whereabouts of his pay-horizon. The generalizing paleontologists, be they seated with the mighty at the place of our Government, or in our state or privately endowed universities, can not then be the "autocrat," but a local paleontologic king will arise.

Many years ago, a well known American geologist collected a handful of fine free brachiopods, which he was certain indicated Middle Cambrian strata. Now, any one who has collected Cambrian fossils in North America need be told no more than this to realize that the geologist was in error, for no one has gathered so much as a handful of free fossils of any kind out of Cambrian strata. But the man in question, seeking confirmation that he was certain would be given him, showed his specimens to Doctor Charles D. Walcott, and when the latter told him

the shells were either of Silurian or Devonian age, the gentleman's geologic world seemed suddenly to have come to an end. A specialist in brachiopods was called in to settle the question, and lo! he said the shells were *Atrypa missouriensis,* and that they clearly indicated Upper Devonian time. And the Government geologist thought he had Middle Cambrian! Later on he found out that he had an overturned section, and that a little paleontologic knowledge would have saved him a season's work.

Again, Doctor A. C. Peale never geologized in the Rockies without having in his outfit a copy of Dana's "Manual of Geology," and each night he identified as best he could by the aid of this book the fossils he had gathered during the day. And Peale, even as a pioneer geologist on the Hayden Survey, made no glaring errors. And still another instance, a paleobotanist who knows his fossils well, and who can do more with the plants of the Coal Measures, than can the paleontologist working on the invertebrates discovered several million tons of anthracite that none of the coal companies knew of. When he realized that this unknown wealth was lying at his feet, he wondered what he should do, resign his Government position and become a coal operator, or stick to it and be a mere honored paleontologist. He decided to stick, and to-day he is Chief Geologist in the institution that gave him his start in paleobotany and stratigraphy.

In some of the oil fields, we know that pools of petroleum or gas come in on erosion planes, now the deep-seated disconformities. On such contacts one also expects overlapping of formations, and all the more so if the petroliferous areas are near former shore-lines. How is any geologist to guard against the possible pitfalls here in correlating the horizon from well to well? In such cases lithology may be but another trap for him, and if he is far-seeing and cautious, he will seek for fossil evidence. But who is collecting fossils from bore holes? As stated before, less than 5 per cent of the deep wells have good published records, and probably less than 1 per cent of the underground stratigraphy is based upon paleontologic evidence secured from these deep wells.

It may be asked, what can the paleontologist do with small

chips of limestone in which the organisms are usually fragmentary or minute forms? Just such chips have recently revealed to Joseph A. Cushman, on the basis of foraminifera, that the Cenozoic formations of the entire state of Florida are thinner than nearly all geologists had assumed, and the far more astonishing fact that there is no Upper Cretaceous here, but that the Eocene rests directly on the Lower Cretaceous. Undoubtedly much could be done also with the Foraminifera of the Pennsylvanian. Ulrich and Bassler have repeatedly identified well known horizons on the basis of bryozoa contained in small chips of limestone less than one-half an inch across taken from deep wells. Professor Orton used the method of micropaleontology long ago in the Ohio oil fields, and if it were persistently pursued by the petroleum geologist, backed by the specialist in paleontology, we would soon have a far more detailed and definitely ascertained underground stratigraphy than we now have. We do not ask the petroleum geologists for the impossible in wanting free fossils by the peck, but when you can, let us have all the chips you can get from definitely known horizons. There are probably untold possibilities of value in micropaleontology, a field of endeavor in which little has yet been done in America.

Varying Underground Structures: In regard to underground structures, let me direct your attention to the possibilities of several periods of crustal deformation in any given area, and, further, to the well known fact that folding or mountain-making, like sedimentary accumulation, is a long-drawn-out process. It is these orogenic movements, plus the warping and the compensating faulting that goes on during the areal subsidence, that bring about the varying paleogeographic pattern of the seas and the many breaks which are revealed especially well toward the old shore-lines where the ebb and flow of the seas has advanced and retreated. We have long been learning of the late Pennsylvanian diastrophism of Oklahoma and Texas, but the earlier one following Morrow-Bend time, and especially that at the close of the Mississippian, are not so clearly seen. Yet we know of the 10,000 feet of early Pennsylvanian strata in Arkansas and Oklahoma, telling of an earlier rising of mountains. Recently Butts has said that about 10,000 feet of strata were also laid down in earliest Pennsylvanian time in Alabama. All of which

are older than any of the same period in Illinois. This is further evidence of mountain-making at the close of Mississippian time in Alabama. We seem now to see a marked period of diastrophism during the close of the Mississippian, and another lesser one after Morrow-Bend time, affecting much of the south and southwest, and farther to the north warping the lands into basins into which the later Pennsylvanian seas spread in their migration from the far west and the Pacific. In other words, the states of Texas, Oklahoma, and Arkansas have undergone an orogeny that is of the Appalachian kind, i. e., a series of pushes widely separated in time, each of long duration, and together going to make up the structure and the variable formations that the deep wells are now revealing. It therefore follows that the sub-surface of the Pennsylvania strata will not be exactly like that of the underlying Mississippian, but that one should rather look for far more locally complicated structures and a different paleogeography in the latter rocks, because they have undergone at least two independent series of movements.

These are the larger and more easily ascertained structures, but what of the many crustal warpings and local faultings that have over and over again changed the pattern of the sea-ways, and brought on the many disconformities?

On the other hand, the inherent structures of the Comanchean are probably not at all indicative of the underground forms of the Paleozoic formations, except where the entire masses have been moved together through warping and faulting.

Kinds of Strata with Petroleum: One of the marked peculiarities of petroleum occurrences is their association with marine strata. Certainly no one thinks of drilling for oil in igneous rocks (though it actually occurs in such in one small area in Texas), or even in metamorphic formations or the highly deformed ancient strata. Where are there large pools of oil in strictly fresh-water deposits? Does any sane geologist think of drilling in the Connecticut Valley sandstone, the Red Beds of Texas and Oklahoma, or the Old Red sandstone of Scotland? Petroleum is not even found plentifully in the Coal Measures of the Appalachians, where there are many superposed coal beds, for here the formations are usually alternations of estuarine and fresh-water beds, though deposits of more nearly marine waters

are interbedded with them. Quite otherwise, for the great bulk of the Pennsylvania oils have come from the older marine Devonian formations. On the other hand, who but a "wild cat" would seek for petroleum in red beds thousands of feet thick, or in those having an abundance of sea-laid gypsum and salt formations? Clearly the red color alone is a warning signal that the hydrocarbons have all been oxidized during the time of sedimentation. Again, the dolomites in general, because of their diagenesis or replacement changes at the time of their accumulation, can hardly be the situation for much petroleum. They are the deposits of very shallow and warm waters replete with oxygen; the crystalline and cavernous dolomites may, however, be the best of storage reservoirs for petroleum. Shallow-water marine deposits which are replete with sun-cracked beds, rain-pitted surfaces, intraformational conglomerates, and rippled formations, such as are common in the Ordovician, have been too near the atmosphere during their formation for the storing of the hydrocarbons, or, for that matter, for the thriving of an abundant marine fauna. It is in the carbonaceous or black shales and the dark to black limestones, laid down in areas of little water circulation—the stagnant areas of the seas, with more or less foul bottoms and sulphur bacteria—that one finds vast accumulations of the solid hydrocarbons.

Seemingly, therefore, the place to seek petroleum is in any arched or faulted marine sedimentary series having more or less of dark sediments, in connection with sandstones or other storage rocks, and it does not matter whether one can see the original organisms as fossils or not. Thick and almost pure limestone may be the end-result of bacterial activity, and the hydrocarbons of a black shale may be due to other kinds of bacteria and other micro-organisms. The hydrocarbons, after all, are an end-result of macroscopic and microscopic organisms, animals and plants, undergoing chemical change, either while alive or after death, and they are made at the time of the deposition of the strata. The exuding oil globules of organic metabolism, and those of decomposing bacterial processes as well, are caught up by the clay particles in the muddy waters, and falling with these to the bottom of the seas, are stored up in solid form in the strata. Mr. Alexander McCoy informs the writer that apparently some slight movement of the

strata must take place, in order to change the solid hydrocarbons into the liquid or gaseous condition. Then the locally migrating waters, through the differences of capillarity in the shales and sandstones, draw the volatile parts from the former into the latter or other porous strata as the natural reservoirs. The hydrocarbons in liquid or gaseous form are fleeting materials that work themselves through the strata by the aid of water and the fissuring of rocks, and eventually the more volatile parts may escape into the air, out of which in the main the plants originally took them. Therefore any violently disturbed area of *ancient* rocks will have no commercial quantities of oil or gas, because of the highly fractured conditions of the strata, and when they are present in such disturbed formations, the rocks are of Cenozoic or late Mesozoic age. The California and the Mexican oil areas are deformed formations of these times. On the other hand, the greatest gushers of the world are in the youngest strata, as in the Miocene of the Baku area and of the coastal area of Texas. In the more flat-lying strata of the great interior of North America, where the anticlinal and faulted structures are due in the main to warping, we now know that petroleum is present in rocks as old as the Ordovician. And with this knowledge, one can see no reason why commercial hydrocarbons should not be found in similarly deformed strata back at least to the beginning of Cambrian time.

Strata usually the Deposits of very Shallow Seas: I would like to impress you with my belief that all of our Paleozoic inland seas were very shallow waters, whose depths rarely exceed several hundred feet, and apparently were more often less than 150 feet. In such seas the sunlight penetrated in strength to the bottom, and the possibility for life, both of plants and animals, and of forms both minute and large, was good. And when the waters were clear, in good circulation, and not turbid or stagnant, there was an abundance of bottom life. In all waters, the winds, and especially the storms, push up waves, which in the shallow seas are often of sufficient height to easily attain the bottom through their rolling and downward motion; and there thus developed in such sea-ways not only the well oxygenated waters so desirable for life, but, what is equally important for the petroleum geologist, currents that moved about the sedi-

ments of the bottoms. These currents with their undertows may have moved sands far from shore and laid them down as long and more or less narrow lenses. Such masses of sands had their longer axes more often in accordance with that of the shore, but undoubtedly in places adjacent to headlands there were built up spits, bars, and banks, whose axes were at angles variable to that of the shore. We may accordingly expect in our great inland or epeiric seas, and especially in the areas of the geosynclines, a very variable sedimentation, largely muds interbedded with many more or less local lenses of sandstones and a limited amount of earthly limestones. However, in the American epeiric seas there appears to be always more than 5 per cent of limestone present, the theoretically predicated amount derivable from igneous rocks, and this is a factor that has helped to augment the petroleum residues of organisms.

Importance of Paleogeography: I have not canvassed the geologists of the midcontinent oil fields to find out what attention they are giving to paleogeography as a means toward predicating where the greatest pools of petroleum should occur, but I do know that at least one large company is deeply interested in this study, and that I have sold many a copy of my "Paleogeography of North America" to the geologists in this section of the country. When every oil geologist knows that thin sandstones are the chief reservoirs for petroleum, that they are often laid down in the form of elongate lentils, and that the sandstones are essentially near-shore or current deposits, one would think that each of these workers would be thinking strenuously and long about the ancient geographies, and especially regarding the whereabouts of the shores and sources of sedimentary supply. As sands are delivered to the seas by the rivers, and as the currents of rivers build up deltas that are expanding seaward, there is brought about an interference in these regions between the currents of the rivers and those of the marine waters. Consequently, in the vicinity of rivers one looks for spits, bars, and banks built of sands, and the presence of these in turn produces sheltered or current-less stagnant areas where accumulate the blue and black muds, some of which are reeking with decomposing matter. It seemingly is the carbonaceous shales that have been throughout

the geological ages the chief source from which the sandstones get their supplies of petroleum.

Every large oil-operating company should have its own paleogeographic maps depicting the probable river mouths and the shorelines in their fields of operation. And each oil field is a paleogeographic problem by itself, though it also has a wider setting in the general geography of the time. It is, however, useless to make single maps for an entire system of rocks, for then the time depicted is so vast that the slowly migrating shores may have wandered back and forth several times and probably across hundreds of miles of territory. What is needed are paleogeographic maps, each of a very limited time and at most of not more than one formation, and these should not be merely "sand maps," for such are but the first step in ascertaining the probable ancient geographies. Here, then, is to be developed a wholly new study in our science, which is to record the petrogenesis of formations combined with the results attained by the oceanographer and the marine studies of the biologist in their work on the epicontinental seas of to-day. If all of the petroleum geologists since the early days of oil discovery in Pennsylvania had been making such maps, what a paradise they would be for a paleogeographer to revel in.

Importance of Formational Contacts: Allow me to remark a little on geologic contacts. Even in the open light of day, geologists will vary greatly as to their interpretation of a given contact between two deposits. In a given section, one worker will see no break, and another will see one which means to him that elsewhere thousands of feet have been laid down during the time of the break. I could show you pictures of many exposures where formations lie superposed and seemingly are of continuous deposition, yet their included fossils demonstrate breaks with not only one or more formations absent, but even with one or more systems of strata, lacking. Since all of this is true, how much more difficult must be the interpretation of deep well logs where nearly all the records are of a most superficial petrologic character and without the backing of the entombed fossils. Not only are formations known to thin and thicken, but entire series of strata do so, and this is the best sort of evidence of overlapping formations and the approach to shore-lines.

I am told that the Strawn, for instance, varies between 20 and 4,000 feet, and yet the average geologist sees no break between its parts, and sometimes not even between the adjutant series, the Bend below and the Canyon above. Not only would I look for breaks on either side of the Strawn, but I am willing to believe that you will find such even within the Strawn itself. I am told, also, that the Bend series varies between 100 and 970 feet, and that it rests upon the Ellenberger dolomites, the top of which is of early Ordovician age. Here again I would be very skeptical that all the strata of northern Texas between the Ellenberger and Strawn are of Bend time. At the bottom of the Bend series in northern Texas and southern Oklahoma, the chances are not only good, but even very good, that Mississippian formations will turn up. From north Texas, one goes into the geosyncline of Oklahoma and Arkansas. These as yet unlooked-for strata in northern Texas, if actually present and attainable by the drill, may be oil-bearing, because they are sure to contain black shales and sandstones. Sooner or later some test well should be sent down here so that the oil geologist may get his underground bearings in northern Texas.

I have dwelt on contact phenomena partly because of the great advances that can be made, by their proper interpretation, as to the geologic succession in the areas studied, but mainly because old erosion surfaces are often the planes for oil and gas migration. It is now a well-know fact that strata on either side of a disconformity—and they are all old eroded surfaces—may be very dissimilar in their rock make-up, because above one of these contacts there begins a new series of deposits that may be a complete sedimentary cycle, starting with sandstones, passing into shales, and ending with limestones. These are phenomena favorable for the oil seeker.

Wells for Recording: The drilling geologist could do untold good in stratigraphy if he would every now and then set aside a given well, the log of which is to be gathered by a geologist for scientific purposes. Stratigraphy nowadays studies the texture and the physical and organic modes of composition of the sedimentary strata, plus their order of superposition or time relation as determined by the state of evolution of the contained fossils. In these wells for scientific recording, therefore, the log

should be kept with great care and backed up with an abundance of samples so numbered as to agree with the log. Let us have from all the horizons a tumbler full of the unwashed well slush, and as many washed-out chips as possible, especially from the horizons that have fossils. Never mind how unpromising the fragmentary fossils look, let us have the chips that contain them. Some of these records should be presented to those universities which have students preparing to be petroleum geologists, and might be the material on which the candidates for advanced degrees would base their theses. In some of our laboratories, we have the men to teach the significance of stratigraphy, oceanography, paleontology, and the petrogenesis of stratified rocks, along with practical geologists and engineers to tell the student how the valuable things of the earth are taken out of it. Besides all this stimulation, we have the necessary material for comparison, and the books relating the experiences of our associates and predecessors.

I occasionally read logs of deep wells, and pardon me if I say that at times I laugh over the great knowledge I obtain when I repeatedly read of the superposition of "quicksand, sand, water, slate, blue shale, hard gumbo, white, gray, or black limestone," etc. Such a log may mean a great deal to the man who made it, but as a printed record for the laboratory worker who seeks to unearth its wider significance, this information is useless. Many hundreds, probably thousands of such well records have been printed, and in many cases not even an historical correlation is presented. It is like giving a paleontologist a handful of fragmentary fossils from many horizons, without any field record, and expecting him to tell the exact age of each of the different strata from which they came. In the wells drilled for geologic record, let us have all the detail possible, and please describe the stratigraphic sequence with the contained fossils, as the stratigrapher does the visible sections. If of the million or so wells that have been drilled, only 10 per cent had been carefully described, what a wonderful and detailed historical geology would be ours! I am glad to note that so good a petroleum geologist as Dorsey Hager, in his book, "Practical Oil Geology," says: "By far too little attention is paid to logs" (p. 133).

In conclusion, since the petroleum geologist has forced himself into the oil-drilling fraternity, may not we paleontologists be allowed and even asked to assist, not only in order to bring about a better understanding and solution of the petroleum problems, but even more so in order to garner up for posterity the stratigraphic knowledge gained by the petroleum workers? For only in union of the geological fraternity is there strength of purpose and least chance of failure.

STRUCTURAL CONDITIONS IN THE OIL FIELDS OF BEXAR COUNTY, TEXAS.

By E. H. Sellards, *Austin, Texas.*

Bexar County lies at the west margin of the Coastal Plains in south central Texas about 122 miles from the Gulf Coast. The Balcones Escarpment which divides the Coastal Plains from the High Plateau passes through the northern part of the county. The formations exposed at the surface include those of the Lower and Upper Cretaceous and the Lower Tertiary, as well as some river gravel deposits of the Pleistocene.

The oil fields are found toward the southern part of the county, south and southwest of San Antonio. Although somewhat scattered, the producing wells, all of which are small in point of production, may be grouped into about four or five more or less well defined fields. Of some of these producing areas structural data more or less complete is available while of other areas there is at the present time practically no data as to structure. The Alta Vista field lies about eight miles due south of San Antonio on the west side of the Pleasanton road. The Mission field lies about three miles due west of the Alta Vista field, or about twelve miles slightly west of south of San Antonio. The Somerset field is near the Bexar-Atascosa county line 18 miles southwest of San Antonio. A gas and oil field lies between Leon and Media Creeks from eight to twelve miles southwest of San Antonio. To this field no name seems to have been applied although it is referred to, locally, as the "gas" field. (A number of the wells of this field are on what is known as the Hamilton-Swain land.) South of the Medina River, three or four miles south of the Mission field several wells have been brought in recently. Several of these wells are located on the Swearangen land. A few additional wells are found in the county not included within any one of the areas mentioned.

The production in this county is small. Some of the wells of the Alta Vista field are reported to have produced as much as 200 barrels per day when first drilled several years ago.

Five wells are now producing in the Alta Vista field, of

which one flows and four are pumped. In and near the old Mission field there are about seven small producing wells at the present time. In and near the old Somerset field within Bexar County, about 50 small wells are now producing. All of these are small wells, producing from two or three to five or six barrels per day. In the Atascosa County extension of the Somerset Field, however, some of the wells are reported to be producing 30 bbls. per day. All of the oil in this county is obtained from the Upper Cretaceous; in the Alta Vista and Mission fields, from the Austin Formation, in the other fields, chiefly from the Taylor formation or from the Taylor and Navarro formations. The oil from the Austin chalk is a heavy oil, 14 or 15 Baume, while that of the Taylor and Navarro formations is much lighter.

Thickness and Distribution of the Oil Bearing Austin Formation.

As already stated the oil of the Alta Vista and Mission fields is obtained from the Austin formation. The upper part of the Austin consists of marl and chalk beds, usually blue in color when unoxidized and frequently described by the driller as clay or shale. At a lower level, are white chalky beds often referred to as "magnesian" limestone. In the lower part of the formation are heavy ledges of limestones. The thickness of the Austin formation is best determined from well records, as no locality has been found within the county at which the full thickness of the formation can be measured at the surface. On the other hand it is extremely difficult to tell from the well logs when the drill passes from the Taylor to the Austin. The most trustworthy measurements of the formation are those obtained from wells known to be located near the contact line on the surface of the Taylor and Austin formations. The measurements of the formation obtained in this way indicates a thickness of at least 300 feet or probably somewhat more than 300 feet (Government well at Aviation Post. Waring well, Schertz well, Goforth well).

According to the well logs the white chalky phase of the Austin formation is entered by wells at the North side of the Alta Vista field at a depth somewhat below 1,000 feet and the oil is obtained at about 1,025 to 1,075. At the South side of the field owing to a small fault, the oil is found somewhat deeper, about 1,100 feet. When drilled below the oil producing horizon sulphur water comes into the wells at from 1,050 to 1,250

feet. The sulphur water probably comes from near the Austin and from the Eagle Ford formation.

In the Mission field the heavy oil comes apparently from about the same level in the Austin formation as in the Alta Vista field. In each of these fields there are showings of lighter oils in the formations above the Austin.

Taylor and Navarro Formations.

The Taylor and Navarro formations from which oil is obtained in the Somerset and some of the other fields in this county consist chiefly of marls, clays and shales. The thickness of these formations can be only approximately estimated, since it is difficult to recognize in well logs either the dividing line between the formations or the top or bottom of either formation. In the Alta Vista field the wells, beginning in the Tertiary enter the Austin formation as already noted at between 800 and 900 feet. The thickness of the Tertiary formations at this locality has not been determined. It is possible also that a part of the Navarro formation has been removed by erosion previous to the deposition of the Tertiary. Hence no very satisfactory measurement of the thickness of the Upper Cretaceous formations has been made in this field. From the fact that Green sands similar to those of the Navarro formation and showings of oil are found within 200 feet or less of the surface, it seems probable that the Tertiary formations overlying the Alta Vista field are less than 200 feet thick and that the Navarro and Taylor formations have a possible thickness of between 600 and 700 feet.

In the gas and oil field south of Leon Creek and west of the Frio road, the wells start in the Navarro formation, probably somewhat below its top. From the record of well No. 2, Hamilton and Swain land, it seems probable that the white chalky phase of the Austin formation was entered at 764 feet from the surface. From this record it appears that 600 or 700 feet is to be referred to the Taylor and Navarro formations. However, in this field it is as usual difficult to locate the base of the Taylor. A well on the Reder property shows a stratigraphic interval of about 1279 feet between the green glauconite sands supposed to represent the Navarro formation and the Georgetown-Edwards limestone. Deducting the known thickness of the Del Rio, Buda

and Eagle Ford formation and the approximately known thickness of the Austin there remains for the Taylor and Navarro formations, a thickness of about 800 feet, when fully developed.

In the Somerset field on the property of the Kurz Oil Company, the soft chalky white phase of the Austin formation is reported at a depth of 1450 feet. The Tertiary formations are at the surface in this field, but at a depth of about 500 feet on this property there is found a green glauconitic sandy shale which possibly indicates the Navarro formation. Assuming that the top of the Austin formation is somewhat above the white chalky phase, there is a suggested thickness of the Taylor and Navarro formations in this field of over 700 and probably less than 900 feet. The oil producing horizon at this locality lies at about 900 feet from the surface, and hence near the top of the Taylor or base of the Navarro formation.

The Eagle Ford formation, which has showings of oil, but is not known to be productive in commercial quantities, is thin in this county. Its maximum thickness does not appear to exceed 50 feet, and its average thickness as reported in well logs is from 25 to 35 feet.

Estimated Thickness of the Cretaceous in Bexar County.

The whole thickness of the upper Cretaceous in this area, including the Eagle Ford, Austin, Taylor, and Navarro formations, on the basis of the estimates that have been given, is somewhat in excess of 1,000 feet, and probably not more than 1,250 feet.

The entire thickness of the Lower Cretaceous in this county, including the Travis Peak, Glen Rose, Comanche Peak, Edwards, Georgetown, Del Rio and Buda formations, is certainly more than 1,700 feet and may be in excess of 2,000 feet. This estimate is based in part on a well on the Waring estate on the Bandera Road about 7½ miles northwest of San Antonio. In this well the Buda formation was reached at 400 feet from the surface, while at 2,700 feet the drill was still in materials that from the description given in the log seems to represent sands of the Travis Peak formation or of the Trinity sands. Whether this well which was drilled to a depth of 2,853 feet passed entirely through the Cretaceous or not is not known, as there is no record other

than the log of the well. The deep well on the Leon Springs Military Reservation, starting one or two hundred feet below the top of the Glen Rose formation passed through the Cretaceous and into shists at 1,010 feet.

Upon these estimates the whole thickness of the Cretaceous system as developed in Bexar county appears to be between 2,700 and 3,250 feet.

Structural Conditions.

With these general conditions stated it is possible to pass to a consideration of the structural conditions in this area. In order to place more exactly the relative position of the several small areas producing oil in this county I have indicated their location in a general way on the accompanying map. This paper is listed on the program under the title, structural conditions in the oil fields of Bexar county. The nature of the data available, however, is such as to make it necessary to discuss structural conditions in a somewhat larger area in this county. The discussion is based on work done for the Bureau of Economic Geology of the University of Texas, and the paper is presented with the consent of the Director of the Bureau.

In general the structural conditions in this county are well known from the work of Hill and Vaughan and others and probably are not unlike those of other counties in Texas lying at the inner margin of the Gulf Coastal Plains and crossed by the Balcones fault zone. Bexar County, however, lies near the turn of the fault zone, where its direction changes from about north 60 degrees east to approximately eastward. Heavy faulting in this part of the state at the north margin of the fault zone is well known at the inland margin of the fault zone. It is known also that other faults parallel more or less the main fault. The chief problem for additional observation is to find to what extent these secondary faults are developed, and to what extent there is or may be folding or other structural features accompanying the faulting.

Faults.

The structure in Bexar County is affected as already stated in a large measure by faulting. Aside from the first or large fault of the zone of faulting there are many others farther to the

south which more or less parallel this one. A few of these have been located, and many undoubtedly exist that have not been located. The amount of throw of these faults varies from a few feet to 500 or 600 feet. The downthrow in some of the faults is at the north side, but the usual downthrow and the maximum downthrow is to the south. The change in level of the formations due in part to faulting and in part to dip amounts to as much as about 2,000 feet in the first 20 miles south of the main fault or an average of 200 feet per mile. The 2,000 feet referred to is exclusive of the downthrow of the first or main Balcones fault which amounts to as much as 400 or 500 feet. This dip in the formations as will be shown is not continuous or uniform.

A study of the well records indicates that in addition to numerous small faults, three or four heavy faults or narrow zones of multiple faults, may be recognized.

The first of these is the main fault of the Balcones zone in which the Edwards formation is as a rule faulted against the Glen Rose formation. The throw of this fault appears to be between 400 and 600 feet. This second large fault or fault zone lies near the Castroville road at the northwest city limits of San Antonio, and in some way seems to involve the formation of the basins of Elmendorf and West End Lake. The change of level of the formations across this zone amounts to as much as 400 feet in a mile or less. Heavy faulting is again observed crossing near the headwaters of San Antonio River, where the throw is probably as much as 400 feet. Near the south limits of San Antonio is another line of faults or rapid dips where the formations drop either by faults or dips as much as 400 feet in a distance of three-fourths of a mile or less. The data at hand fails to demonstrate that these faults are continuous as equally large faults across the county. On the contrary they seem to pass from strong dips into faults and again into dips or a succession of minor faults. The large fault which comes into the City limits of San Antonio near the Castroville road appears either to be diverted to the south around the nose of the "up-block," which comes in from the northeast or to become divided, one branch passing on either side of this block.

The location of those faults that have been recognized either

upon surface exposure or from well records is indicated in a way on the accompanying map. At least two small faults cross the Fredericksburg road within two or three miles south of the main Balcones fault. One of these is well seen in a cut on the S. A. P. Railroad on the Bacon Ranch property, where the trend of the fault is about N.-40-E. The large narrow block of the Austin formation extending into the city of San Antonio from the northeast is limited by faults, as indicated by surface exposures both on the north and on the south sides. The throw of the fault on the south side of this block, where it crosses the San Antonio River, as already referred to, amounts to as much as 400 feet. A small fault is seen in the Southern Pacific branch line leading to Camp Travis in a cut near the east limits of San Antonio. The trend of the fault as seen in this cut is about N.-60-E. Two wells drilled for the water supply of San Antonio, located near Conception Mission permit the location of a small fault, not shown on the map, having a downthrow to the south of about 50 feet. Crossing the Pleasanton road about 8 miles south of San Antonio is a small fault which trends N. 60 or 70 E. This fault which passes directly through the Alta Vista oil field has a downthrow to the south as indicated by well records of about 50 feet.

Structurally High Areas.

The prevalence of faulting in this area has been described. In addition there is more or less folding. The structurally high areas approximately parallel the Balcones escarpment, and as a rule plunge or nose down to the southwest. Four more or less well marked higher areas or lifted blocks are recognized on surface exposures and on well records. With little doubt other smaller structural areas are present and possibly other large areas lying farther south than those indicated.

The first, that is the farthest north of the pronounced high areas, is a relatively broad structure, the axis of which lies some six miles south of the Balcones escarpment. This high area is recognized both on surface exposures and on well records. On the crest of this structure in the western part of the county the Austin formation lies at the surface, while both to the north and south the Taylor formation lies at the surface. The structure is equally well indicated by well records. The actual level of the

base of the Del Rio formation on the north side of this structure near the west county line is about 90 feet above sea level (well of J. Benke). The same formation three miles southeast of this place lies about 300 feet higher (well of H. Uhl). The axis of the structure appears to lie another mile or two farther south and hence somewhat higher than in the Uhl well. At the east side of the structure the Del Rio has again dropped to about 100 feet above sea level (well at Fullers earth plant). Several well records are available on and near the Culebra road which crosses this structure obliquely in passing from the west county line to San Antonio. The axis of the structure is crossed on this road about 14 miles northwest of San Antonio. Here the Del Rio formation lies at the actual level 675 feet above sea level (well of Mrs. A. Voight). Passing southeast this formation drops down to 100 feet above sea in a distance of six miles (well of A. Skolout). Beyond this well to the southeast is the fault with a downthrow of as much as 100 feet to which reference was made earlier in this paper.

A second well marked "up-block" of the Austin formation is that which reaches into San Antonio from the northeast. This block is narrow being only 2 or 3 miles wide and limited probably on both the north and south sides by faulting. The difference in level of the Del Rio formations on the block and at either side appears from well records to amount to between 350 and 400 feet. This "up-block" approximately parallels the San Antonio-Austin road which is on the block until near the city limits of San Antonio. In this as in the other structures there is a pitch to the southwest by which the Austin formation is carried below surface level near San Antonio.

Immediately west and southwest of San Antonio structural conditions are very much more obscured so far as surface exposures are concerned by the large development of the gravel plain. However, in the bluffs at the south side of Leon Creek southwest of San Antonio surface exposures indicate another structurally high area in which is located several gas and small oil wells. The west or northwest dip of this structure is seen at the Castroville Road crossing of Leon Creek in the bluff below the crossing and also in a heavy ledge of glauconitic sandstone exposed above the crossing. The south or southeast dip of the structure is seen in the bluff on Leon Creek west of the crossing of the Quintana

public road and the I. G. N. Ry. In this exposure the same or apparently the same ledge of glauconitic sandstone exposed at the Castroville road comes into the section and passes below water level near the road crossing.

The well records relating to this structure are much less definite than those relating to the structures last described. It appears, however, that the structure is limited at its north or northwest side by a fault, since near the Castroville road crossing on Leon Creek the formations drop several hundred feet within a short distance. The Del Rio, used as a key formation, is found to drop from 150 feet above sea level (Hartman well) to 462 feet below sea level (Clamp well) within a distance of two miles or less.

The gas and oil wells in this field terminate in the Taylor or Austin formations and hence do not reach through to a formation the level of which can be entirely and definitely determined. However, from the wells located in the gravel plain on the east side of Leon Creek records are obtained which check and agree with the observations on the surface exposures. Thus in the Allen well at Kelly Aviation field the base of the Del Rio lies at 360 feet below sea level, while in the Clamp and Blank wells from 2 to 2½ miles northwest the same formation lies 100 feet or more lower, or at 462 and 480 feet below sea level respectively. In the opposite direction, to the southeast the formation dips at first slowly and afterwards more rapidly. A well on the Rideer property, three miles south of the gas wells shows the Del Rio formation to lie at the depth of 869 feet below sea level. The dip to the southwest amounting to about 500 feet in five miles. When the data derived from the well records is platted on the map, the area immediately southwest of San Antonio appears as a broad flat topped structure which beyond Leon Creek plunges to the southwest.

The structure next to the south that appears on the evidence of the well records is that of the Alta Vista and Mission Oil fields. In this area records based on deep wells are unfortunately few. However, immediately within the Alta Vista field the chalky white phase of the Austin formation seems quite definitely to be reached at about 1,010 feet. In the deepest well immediately within this field the Buda formation appears to have been

reached, on the basis of samples of cuttings identified by Dr. J. A. Udden, at about 1,270 feet. On this data the base of the Del Rio formation should be reached at about 1,300 feet, or at about the actual level of about 700 feet below sea level. A mile to the northwest, well of Ed. Steves, the Del Rio formation is reported to lie lower by three or four hundred feet, at actual level—1189. In the Roby and Hill well about one mile to the northeast the base of the Del Rio is reported at actual level—1140, while in the Ripps well about one and one-half mile slightly north of east the same formation is reported at 998 feet. To the southeast the formation undoubtedly drops rapidly although the rate of dip has not been satisfactorily determined. The Porch Well at the south end of Lake Mitchell indicated that the formations there lie much lower than in the Alta Vista Field.

Although the records are much less complete than could be desired the Alta Vista field appears to differ in structure from the others in that it seems to be a dome probably elongated approximately in the direction of the structural lines as seen in the other fields. In mapping, the Alta Vista field is shown as continuous with the Mission field. This, however, can not be regarded as certain since the records are too limited. It is quite possible that the two fields may be separated by a structurally low area.

In the Somerset field the data on structure are unfortunately very limited. In that part of the area lying from ½ to 1½ miles southeast of the village of Somerset the dip in the strata seems pretty definitely to be to the southeast. On the Kurz property near the Artesian Belt railroad about 1½ miles from Somerset the dip was found according to well records to amount to 40 feet in about one-third of a mile. The Austin formation as already noted appears to have been reached in a well on this property at about 1450 feet. At 1650 feet in this well a small amount of heavy oil was obtained which possibly may have come from the Eagle Ford or from near the base of the Austin.

In the new wells of the Brownie Oil Company on the Swearangen land south of the Medina River the dip of the formations likewise is reported to be in general toward the southeast.

By way of summary in regard to structural conditions as a whole it will be noted that there is apparently a tendency for

the structures to be unsymmetrical, the longer slope being to the southeast, while the shorter and more abrupt slope is at the northwest side. The producing oil wells likewise are apparently more commonly located on the southeast rather than on the northwest slopes of the structure. This is probably true of the Alta Vista field, and seems to be true of the Mission field. The wells of the gas field west of Leon Creek are near the assumed position of the axis while some of the small oil producing wells are southeast of it. The wells of the Somerset field as already noted are on a south or southeast dipping slope. The symmetry of the structures plats out on the evidence of well records for all of the large structures on which any data exists. It would seem therefore that the favored location of the wells in this area is on the southeast slope of the more or less well marked and usually asymmetrical structural areas.

SOME OIL FIELD WATERS OF THE GULF COAST*

By G. Sherburne Rogers.

Contents.

Illustrations

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Introduction.

The undesirability of permitting water to invade oil sands has become an established principle with most American oil operators during the last two decades, and many refinements in technologic practice have been devised in order to prevent such invasion. In some regions the invasion by extraneous water is less harmful than in others, but unfortunately it seems that water is most harmful in those regions in which it is most difficult to exclude. It is impossible to guage the extent to which water intrusion has affected the production of oil in the Gulf Coast fields for they have always been afflicted by water troubles, but if water conditions could be improved it appears certain that operating expenses would be reduced and probable that production would be materially increased.

The systematic exclusion of water from the oil sands, like all similar technologic problems, should be based on a knowledge of geologic conditions—in other words, the relative positions of at least the water and oil sands must be known. In the Gulf Coast fields an accurate and detailed survey of the underground geology is exceedingly difficult to make, not only on account of the prevalence of the rotary method of drilling, which furnishes a log of very limited value, but because of the lenticularity of the strata, the absence of key rocks, the scarcity of fossil horizons, and the intense and complicated structure which characterizes the salt domes. Partly for these reasons many operators believe that most of the water actually occurs in the oil sands and therefore cannot be avoided, but where careful geologic studies have been made it has been found that the water is chiefly extraneous. The Rio Bravo leases in the Saratoga field, for example, have as a result of the investigations of E. T. Dumble and his associates been kept remarkably free from water troubles; and similarly in the Goose Creek and Edgerly fields the detailed studies of H. E. Minor of the Gulf Production Company have furnished a comprehensive basis for the exclusion of water and have resulted in increased efficiency in the production of oil.

When purely stratigraphic studies are not conclusive, however, investigations of the chemical character of the waters them-

selves are often of value. In the California fields[1], for example, the change in character of the waters as the oil sands are approached is sufficiently pronounced to permit the use of the analysis as an index of the general horizon of the water; in some of the Midcontinent[2] fields the waters occurring above and below the main producing sands are very different in composition, and in the Russian[3] and Roumanian[4] fields analyses of the water have also proved of value. Accordingly, the writer, in beginning an investigation of the salt dome fields for the U. S. Geological Survey, collected a number of samples of the oil field waters in order to ascertain their general character, and to determine if possible whether they vary in composition according to depth or stratigraphic horizon. This paper presents the analyses of such samples as have been examined and discusses their significance and the possibility of applying them in practical oil-field work.

The samples were collected through the co-operation of a number of geologists and operators, who generously contributed also a great deal of information not used in this paper. The writer takes this opportunity of gratefully acknowledging his indebtedness to Messrs. Alex. Deussen, F. A. Provot, E. T. Dumble, Wm. Kennedy, and J. W. Bostick, L. P. Garrett and H. E. Minor, C. N. Scott and E. G. Woodruff, J. R. Suman and F. B. Plummer, H. T. Stait, T. W. White, R. W. Pack, D. D, LaFavor, E. B. Hopkins, F. F. Kendall and many others.

General Geology and Hydrology of the Coastal Plain.[5]

The rocks exposed on the Coastal Plain of Texas and of

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[1]Rogers, G. S., Chemical relations of the oil field waters in San Joaquin Valley, California: U. S. Geol. Survey, Bull. 653, 1917.

[2]Neal, R. O., Petroleum hydrology applied to Midcontinent field: Amer. Inst. Min. Eng. Bull. 145, January, 1919, p. 1.

[3]Goloubjatnikov, D., Eaux souterraines du gisement petrolifere de Bibi-Eibat: Mem. Comite Geol., n. s. Liv. 141, 1916.

[4] Mrazec, L., personal communication.

[5]A comprehensive account of the geology and hydrology of eastern Texas is given by Alexander Deussen, Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain, U. S. Geol. Survey Water Supply Paper No. 335, 1914.

Louisiana and encountered in the wells drilled in this region, consist chiefly of a great sedimentary series dipping at a low but fairly constant angle toward the coast. The deposition of these beds was interrupted from time to time by land epochs and periods of erosion, now recorded as unconformities, and during certain epochs deposition proceeded concurrently on the land and off-shore, giving rise to continental and marine facies of the same series of beds. The careful surface studies of many geologists have led to the differentiation of a number of formations, though in the ordinary well log it is difficult, unless paleontologic data are at hand, to determine precisely the line of demarkation between one formation and another.

That portion of the Coastal plain in which the oil producing salt domes are located is covered by a mantle of Quarternary deposits and is underlain to the greatest depths reached by the drill by beds of Tertiary age. The important Pleistocene formations are the Beaumont clay and the underlying Lissie gravel, each of which attains a maximum thickness of about 800 feet. The Lissie is underlain by a series of Miocene and lower Pliocene beds of continental origin which were called by Deussen the Dewitt formation and which grade seaward into marine sands and clays. The Dewitt is underlain by the Fleming clay which belongs to the lower Miocene, the Catahoula-Fayette sands of Oligocene and upper Eocene age, and the Jackson formation. The uppermost member of the Claiborne group, the Yegua formation, has been identified at Humble by Deussen, who regards this formation as the probable source of the Humble oil.[1]

The so-called salt domes consist of plugs of rock salt, generally capped by gypsum, anhydrite, limestone and sulphur, which extend vertically through the formations described above and which have caused pronounced but very local deformation of those beds. The origin of the plugs is a moot question; some geologists hold that they were laid down by ascending hot waters, others that they are connected with volcanic agencies, and others that they are due to the deformation of deep-seated salt beds, causing the salt to become plastic and intruding it into the overlying formations. Whatever the origin of the salt plugs may

[1]Deussen, A.: The Humble Oil Field, Texas: Southwestern Association of Petroleum Geologists, Bull. 1, p. 60, 1917.

be, however, it is clear that circulating waters have been important agents in the formation of their cap rocks, and a study of salt dome waters therefore has scientific as well as practical interest.

Hydrologic conditions on the Gulf Coast are—except in the immediate vicinity of the salt domes—comparatively simple. Meteoric waters enter the truncated edges of the formations in the higher land to the north and percolate slowly down toward the sea. At shallow depths circulation is comparatively free and the rocks have been washed clean of much of their soluble mineral matter, but as the waters are carried down the dip to greater depths their movement becomes very slow and the concentration of their dissolved mineral matter increases notably. As some formations are richer in soluble minerals than others the chemical character of a water depends somewhat on the formation in which it occurs; and as the circulation in a region of lenticular strata varies in different beds the concentration of the waters is also somewhat variable. Nevertheless there are few localities on the Coastal Plain in which postable water can be obtained at depths greater than 1,500 or 2,000 feet, and in the belt immediately adjacent to the coast salt water is encountered at very shallow depths.

The presence of salt plugs extending through the bedded formations introduces an element of irregularity into the otherwise simple hydrology of the Coastal Plain. All the waters in the immediate vicinity of the plugs are very salty, and salt water occurs at shallower depths above the plugs than elsewhere. It may be presumed that when ordinary ground water following any one formation arrives at the area of deformation adjacent to the salt plug it is abruptly deflected upward, and that some of it may ascend from a depth of several thousand feet to the level of the cap rock. The consequent decrease in temperature and pressure must cause a change in the chemical character of the water; and as DeGolyer[1] has suggested, the abrupt increase in sodium chloride due to the proximity of the salt mass may cause precipitation of limestone or gypsum. A variety of reactions, many of which are reversible, evidently take place in the cap-

[1]DeGolyer, E.: Origin of the cap rock of the Gulf Coast Salt domes: Econ. Geol., vol. 13, p. 616, 1918.

rock area, but they constitute a problem demanding detailed petrographic and chemical studies.

Statement of Analyses.

Of the analysis given below, numbers 1, 4, 5, and 6 are reprinted from Water Supply Paper 335, page 110. The remainder were made in the laboratory of the Survey by Dr. Chase Palmer and Mr. Benedict Salkover.

In the accompanying tables the analyses are stated first in terms of radicals in parts per million. As the different acid and basic radicals differ in their power to combine with or balance one another, the analyses are also given in terms of reacting value reduced for convenience to a per cent of the total reacting value or concentration of the water. Thus, 1,000 parts per million of chloride means simply 1,000 pounds of chloride to a million pounds of water, but 10 per cent of chloride by reacting value means sufficient chloride to combine with 10 per cent of sodium, or with 5 per cent of sodium and 5 per cent of calcium

In order to summarize the analyses the reactive properties of the waters as defined by Palmer[1] have also been calculated. These properties represent simply the balances existing between the different radicals, which are first grouped according to their chemical nature. For the purposes of this discussion primary salinity may be considered as the distinctive property of a solution of sodium or potassium chloride or sulphate; primary alkalinity that of a solution of sodium or potassium carbonate, bicarbonate, or sulphide; secondary salinity that of a solution of calcium or magnesium chloride or sulphate, and secondary alkalinity that of a solution of calcium or magnesium carbonate, bicarbonate or sulphide. Primary alkalinity can exist only when the alkalies (Na and K) exceed the strong acids (Cl and SO-4) in reacting value, and secondary salinity only when the strong acids exceed the alkalies; hence these two properties are incompatible.

Normal Coastal Plain Waters

Analyses 1 to 6, Table 1, represent various types of what may be called normal Coastal Plain waters. All of the analy-

[1]Palmer, Chase: The geochemical interpretation of water analyses: U. S. Geol. Survey, Bull. 479, 1911; also

Rogers, G. S.—Interpretation of water analyses by the geologist: Econ. Geol., vol. 12, p. 56, 1917.

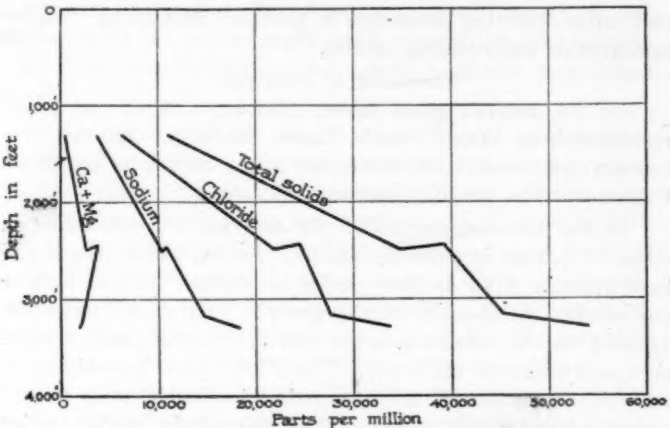


Fig. 1. *Diagram showing increase in the concentration of various constituents with depth in five waters from the Goose Creek field (see analyses 7-11).*

ses except number 3, represent waters from the Lissie gravel, which is the great artesian reservoir of the Texas Coastal Plain; analysis 3 represents water probably from the Dewitt formation.

Analysis 1, representing water from a depth of 406 feet at Thompson, Fort Bend County, and number 2, water from 780 feet on the eastern edge of the Humble field, are very similar in concentration and in character. Both waters are very dilute solutions, low in chlorides and high in carbonates; that is, they are characterized by low primary salinity and by high primary and secondary alkalinity. Analysis 3 is of water to a depth of 1,200 feet on the eastern edge of the Humble field (see fig. 1.), which is more concentrated than the foregoing and also higher in chlorides and lower in carbonates. Analysis 4, of water from a depth of probably 500 feet at Houston, is very similar to number 3. Numbers 5 and 6 are waters from the coastal belt in which all ground water is salty, analysis 5 representing water from Galveston at a depth of 856 feet, and analysis 6 water from Velasco at about 1,100 feet. These analyses show a further change along the same lines of gradation as the first four—i. e., they are still more concentrated and still higher in chlorides and lower in carbonates, being, in fact, salty waters whose chief dissolved constituent is sodium chloride. It will be noted that the

Exhibit A.—Table 1: Analysis of Coastal Plain waters

		1	2	3	4	5	6	7	8	9	10	11
Constituents in parts per million												
Sodium	(Na)	55	69	551	436	1229	{ 1331 }	3800	10300	10700	14800	18200
Potassium	(K)	3.5		23	21	22		Tr.	Tr.	Tr.	Tr.	Tr.
Calcium	(Ca)	42	33	25	26	33	79	450	1700	2700	1400	1430
Magnesium	(Mg)	12	6.5	5.6	12	17	28	120	620	990	690	540
Iron	(Fe)	.15	1.7		.3	2.1						
Aluminum	(A1)	.62			2.2							
Sulphate	(SO4)	3.3	0	0	157	.3				210	120	
Chloride	(C1)	28	21	455	342	1793	2132	6300	21900	24500	27800	33700
Carbonate	(CO3)	12	Tr.	21	19	0	0	0	0	0	0	0
Bicarbonate	(HCO3)	231	233	770	467	384	241	70	600	180	700	400
Silica	(SiO2)	21	34	27	10	17						
		291.57	304.2	1485.6	1255.5	3302.4	3688	11014	34815	39189	45154	54067
Reacting values in per cent												
Sodium		21.5	28.9	45.6	43.6	46.9	45.2	41.8	38.5	34.2	41.9	43.6
Potassium		.9		1.1	1.1	.5						
Calcium		18.8	16.0	2.4	3.0	1.4	3.0	5 7	7.2	9.8	4.5	3.9
Magnesium		8.8	5.1	.9	2.3	1.2	1.8	2.5	4.3	6.0	3.6	2.5
Sulphate		.7			7.8					.3	.2	
Chloride		7.7	5.6	24.5	22.7	44.5	47.0	47.0	49.2	49.5	49.1	49.6
Carbonate		3.9		1.3	1.4							
Bicarbonate		37.7	44.4	24.2	18.1	5.5	3.0	3.0	.8	.2	.7	.4
Properties of reaction in per cent												
Primary salinity		16.8	11.2	49.0	61.0	89.0	90.4	83.6	77.0	68.4	83.8	87.2
Secondary salinity							3.6	10.4	21.4	31.2	14.8	12
Primary alkalinity		28.0	46.6	44.4	28.4	5.8						
Secondary alkalinity		55.2	42.2	6.6	10.6	5.2	6.0	6.0	1.6	.4	1.4	.8

Normal Coastal Plain Waters:

1. Eliza Jones well, Thompson, Ft. Bend Co. Water from Lissie gravel at 406 feet. Analyzed by J. R. Bailey and A. M. McAfee.

2. Texas Co. Landslide well 214, Humble field. Water probably from Lissie gravel at 780 feet. Analyzed by Chase Palmer.

3. Texas Co. Wheeler & Pickens well 18, Humble field. Water probably from Dewitt formation at 1,200 to 1,300 feet. Analyzed by Chase Palmer.

4. Cummings Export Co. well, Houston. Water from 500 feet in Lissie gravel. Analyzed by J. R. Bailey and A. M. McAfee.

5. Texas Ice & Cold Storage Co. well, Galveston. Water from 856 feet in Lissie gravel. Analyzed by S. P. Sharpless.

6. E. D. Dorchester well, Velasco, Brazoria Co. Water probably 1,100 feet in Lissie gravel. Analyzed by H. H. Harrington.

Waters of the Goose Creek Oil Field:

(Analyzed by Benedict Salkover.)

7. Gulf Prod. Co. well Tabb A 6. Water with oil from 1,305 feet.

8. Gulf Prod. Co. wells Stateland Producers 6 and 8. Water with oil from 2,425 to 2,600 feet.

9. Gulf Prod. Co. well Wright A 3. Water with oil from 2,400 to 2,500 feet

10. Gulf Prod. Co. well Tabb fee 7. Water from 3,164 feet, below oil sand.

11. Gulf Prod. Co. well Tabb A 7. Water from 3,296 feet.

Table 2: Analysis of Oil Field waters from Humble and Damon Mound

	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Constituents in parts per million														
Sodium	3595	43300	61000	15200	22000	23900	27300	7300	6700	24200	32400	12800	40800	39500
Potassium (K)	48	Tr.	Tr.	Tr	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Calcium (Ca)	382	1700	5000	1800	2200	1780	1460	1410	1400	1400	1100	530	1660	2100
Magnesium (Mg)	177	220	750	340	450	450	100	100	70	260	230	220	350	400
Sulphate (SO4)	Tr.	1750	900					3010	2400		270			
Chloride (Cl)	6083	70600	105400	25300	40100	40700	45300	11700	11300	41200	53700	21900	63400	61300
Carbonate (CO3)														
Bicarbonate (HCO3)	355	500	300	530	290	600	490	200	280	500	70	180	230	260
Sulphide (S)	6	170						9.8	70					
Silica (SiO2)	69													
	10534	117986	173197	42900	64783	67125	74790	23627.8	22078	67306	87734	35538	106823	103428
Reacting values in per cent														
Sodium	40.9	47.4	44.8	42.5	43.6	44.5	45.7	40.0	39.6	46.1	47.6	46.3	47.0	46.3
Potassium	.3													
Calcium	5.0	2.1	4.2	5.8	5.1	3.9	2.8	8.9	9.6	3.0	1.8	2.2	2.2	2.8
Magnesium	3.8	.5	1.0	1.7	1.3	1.6	1.5	1.1	.8	.9	1.5	1.5	.8	.9
Sulphate		.9	.3					7.9	6.6		.2			
Chloride	48.2	48.6	49.6	49.4	49.8	49.6	49.7	41.7	42.2	49.7	49.8	49.8	49.9	49.9
Bicarbonate	1.8	.2	.1	.6	.2	.4	.3	.4	.6	.3		.2	.1	.1
Sulphide		.3							.6					
Properties of reaction in per cent														
Primary salinity	82.4	94.8	89.6	85.0	87.2	89.0	91.4	80.0	79.2	92.2	95.2	92.6	94.0	92.6
Secondary salinity	14.0	4.2	10.2	13.8	12.4	10.2	8.0	19.2	18.4	7.2	4.8	7.0	5.8	7.2
Primary alkalinity														
Secondary alkalinity	3.6	1.0	.2	1.2	.4	.8	.6	.8	2.4	.6	Tr.	.4	.2	.2

Waters From the Humble Field:

12. Herman 145. Water with oil from 775 feet. Analyst, Chase Palmer.

13. Brooks 2. Black sulphur water with oil from cap rock at 1,167 feet. Analyst, Benedict Salkover.

14. Landslide 216. Sulphur water with oil from sand lens in or just above the black shales, at 1,315 feet. Analyst, Benedict Salkover.

15. Landslide 206. Water supposed to occur with oil at 2,360 feet. Analyst, Benedict Salkover.

16. Koehler 9. Water with oil from 2,955 feet. Analyst, Benedict Salkover.

17. Stevenson 15. Water with oil in sands between 2,714 and 3,246 feet. Analyst, Benedict Salkover.

18. Carroll Oil & Gas Co. well 18. Water with oil in sands between 2,773 and 3,200 feet. Analyst, Benedict Salkover.

Waters From Damon Mound:

(Samples collected at wells of Texas Exploration Co., and analyzed by Benedict Salkover.)

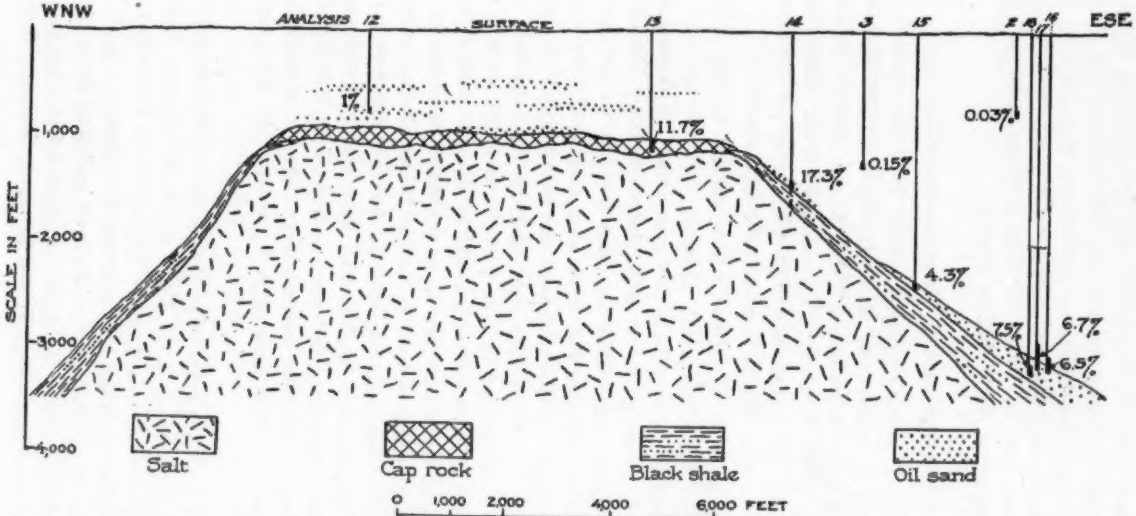
19 and 20. Wells on north side of dome in cap rock. No. 19 is water from about 250 feet, or near top of gypsum, and No. 20 is from about 510 feet or near base.

21. Bryan 4. Water from 1,717 feet, or above oil zone.

22. Masterson 1. Water from 1,720 feet, or in oil zone.

23 and 24. Becker 2. No. 23 is water from 2,948 feet, and No. 24 is from 3,478 feet, both being above the oil zone.

25. Bryan 1. Water produced with oil from 3,470 feet. Temperature 126° F.



GENERALIZED CROSS SECTION OF HUMBLE DOME ¼ AFTER DEUSSEN), SHOWING RELATIVE POSITION OF WATER SAMPLES ANALYZED AND CONCENTRATION OF THE WATERS IN PER CENT (1% EQUALS 10,000 PARTS PER MILLION.

gradation leads toward the typical salt dome waters, which are very concentrated, highly saline, and practically lacking in alkalinity; yet even Velasco water, which occurs at a depth of 1,100 feet directly on the coast and which is the most extreme of the normal waters, can be distinguished at a glance from salt dome waters occurring at fairly shallow depths.

Waters of the Goose Creek Field.

Analyses 7 to 11 represent waters from the Goose Creek field, number 7 representing water from about 1,300 feet, numbers 8 and 9 water from near 2,500 feet, and numbers 10 and 11 water from near 3,200 feet. Two samples from shallow water wells intended for comparison with the deeper oil field waters were unfortunately lost in transit to the laboratory.

According to H. E. Minor, whose careful studies at Goose Creek render him the special authority on that field, the oil-bearing strata are warped in a very gentle and flat dome and the salt plug, if present, lies at unexplored depths. The dip of the strata penetrated within the field itself is so low and the structure so regular that the depth of a sand is a close measure of its stratigraphic position, though the extent to which the producing area as a whole has been uplifted has not been determined. It is interesting to note that the analyses show a fairly regular increase in concentration and in chloride with depth but that otherwise the waters are all very similar in character. All of them are strong secondary saline brines, being essentially solutions of sodium chloride with moderate proportions of calcium and magnesium chlorides and very minor percentages of calcium and magnesium carbonates. They thus differ radically in character as well as in concentration from the normal Coastal Plain waters, in which carbonates are usually the chief constituents.

Figure 1 shows graphically the increase in the concentration of several constituents with depth in the five waters analyzed. Although five analyses are totally inadequate as a basis for working out detailed variation it is apparent that there is a fairly regular increase in concentration with depth and that the horizon of water in this particular field can be estimated at least in a general way from its analysis. It will be noted, however, that num-

bers 8 and 9, which are supposed to occur very near the same horizon, show considerable difference in concentration and it is not known whether this condition is due simply to the fact that one of the waters comes from a higher sand than is supposed or whether it indicates that waters from the same horizon do differ somewhat from place to place.

Waters of the Humble Field.

Analyses 2 and 3 represent shallow waters from the Humble field and numbers 12 to 18 represent waters associated with the oil in various positions above and on the flanks of the dome. Numbers 2 and 3, already discussed, are normal Coastal Plain waters, and the remainder are brines resembling those at Goose Creek in character but exceeding them in concentration.

The top of the salt mass at Humble[1] lies at a depth of about 1,200 feet and is overlain by a cap rock of limestone and gypsum, which varies in thickness but generally does not exceed 100 feet. The flanks of the salt plug dip steeply and are covered by a black shale formation which decreases in thickness as the cap rock is approached, and disappears at about the level of the cap. (See fig. 2.) On the east side of the dome the black shale at depth is overlain by a series of sands, but these thin out and disappear near the 2,500 foot level, and elsewhere the black shale is overlain by a series of gumbos with occasional sand lenses. The bulk of the deep oil is produced from the sand series but a little light oil is obtained from the black shale. Most of the shallow oil is derived from the almost flat-lying sands above the cap, but the cap rock itself, which formerly yielded the great production, still produces considerable heavy black oil.

As geologic conditions at Humble are far more varied than those shown by the sands so far penetrated at Goose Creek (which are probably equivalent simply to the flat-lying sands above the cap at Humble) it is evident that no general connection between the depth and the composition of the waters can be expected. Number 2, which occurs at a depth of 780 feet, in the first five waters are primarily alkaline in character and that

[1]An excellent description of the Humble oil field has been given by Alexander Deussen. The Humble oil field, Texas: Southwestern Assoc. of Petroleum Geologists, Bull. 1, p. 60, 1917.

the sixth is just over the dividing line, being only slightly secondary saline; in other words, the alkalies in the first five waters exceed the strong acids in value and the waters, like sodium carbonate solutions, give a strong and permanent alkaline reaction.

The analyses thus indicate that the normal shallow ground waters in this region are moderately dilute solutions which are primarily alkaline in character, but that concentration and salinity increase and alkalinity decreases with depth, and also with proximity to the coast. As will be shown below, this line of sediments off the flanks of the dome, is a dilute, alkaline, normal water, whereas number 12, which occurs at the same depth directly above the salt mass, is about thirty times as concentrated and is a secondary saline brine; and similary number 13, occurring in the cap rock at 1,167 feet, is about eighty times as concentrated as number 3, which is from the same depth about 4,000 feet away. (See fig. 2.) Numbers 2 and 3, if considered together. however, show increase in concentration with depth and numbers 12 and 13 show similar variation, indicating that in waters occurring under comparable conditions this relation may be expected. Number 14, water which is supposed to occur either in or just above the black shale at 1,300 feet, is by far the most concentrated of all, being a 17.3 per cent solution, but this may perhaps be due to direct contamination by salt, for the well was originally drilled into the salt mass and the bottom may not have been perfectly plugged. Numbers 16, 17, and 18 represent waters from widely separated wells deriving their production from about the same horizon, i. e., from the zone of oil-bearing sands on the east flanks of the dome. These waters are very similar in character and range in concentration from 6.5 to 7.5 per cent, suggesting that within this belt a definite relation between composition and depth or horizon may exist. Analysis 15 represents a water which is considerably less concentrated and which apparently occurs in the same sands much higher up the slope.

If analyses 2 and 3, representing the dilute alkaline normal waters, and number 13, representing cap rock water, are excepted the analyses show little variation in the proportions of individual constituents. Calcium and magnesium bear a pretty constant relation to sodium in all the waters, ranging in value

only between 8 and 14 per cent of the total reacting value of the water; and the carbonates are invariably of very minor importance. Number 13, the cap rock water, and number 14, which is water from the black shale (possibly contaminated with water from the salt mass) are the only ones that contain sulphate. Neither of these waters is saturated with respect to sulphate, however, which is strange, especially in the case of number 13, which issues directly from the gypsiferous cap rock. Number 12, occurring in the sands above the cap rock, contains a trace of sulphide and number 13, the cap rock water carries 170 parts per million.

Although it can not be predicted from these analyses how closely the composition of the water is dependent on its horizon it is evident at least that the Humble waters will repay further study.

Waters of Damon Mound.

Analyses 19 to 25 represent waters from Damon Mound, the first two occurring in the cap rock and the remainder at various horizons on the south flank of the dome. Analysis 1, representing a normal water from Thompson, about 18 miles northeast of Damon Mound, is interesting by way of comparison.

Damon Mound differs from Humble in the fact that the salt mass has approached close enough to the surface to cause the formation of a conspicuous mound about 75 feet high and 2 miles in diameter. The salt is encountered at about 550 feet, above which is the cap rock, consisting of about 375 feet of gypsum and anhydrite with some sulphur, and with an overlying layer of limestone. The flanks of the salt mass dip at angles much steeper than those at Humble; in one locality the dip is over 60 degrees, suggesting the drag of a peripheral fault. In the small oil field on the southern edge of the dome the dip of the sands appear to average about 45 degrees though the dip doubtless decreases farther away from the salt mass. Pockets of oil have been found in the cap rock but all commercial production is derived from these steeply dipping sands on the flanks of the dome.

The writer has not had opportunity to attempt to work out the complex structure of Damon Mound and is unable to fix definitely the horizons of the various waters. It appears, however, that number 21, from a depth of 1,717 feet, is considerably

higher stratigraphically than number 22 from the same depth, a fact which might also be suspected from its notably lower concentration. Numbers 23 and 24, which are from depths of 2,948 and 3,478 feet in the same well, are very similar in character, but the shallower water is only one-third as concentrated as the deeper. and is only about half as concentrated as numbers 21 and 22, which occur at still shallower depths but much nearer the salt mass. Number 25, representing water from 3,470 feet, has about the same concentration as number 24, though it appears to be a somewhat lower water. The analyses indicate that although the waters are very similar in character they differ considerably in concentration and suggest that this variation follow a definite rule.

Analyses 19 and 20 represent black sulphur waters from the cap rock, number 20 occurring at about 250 feet or near the top of the gypsum and number 21 at 510 feet or near the base of the gypsum and the top of the salt. These waters differ but slightly in concentration though occurring at very different depths, a fact which suggests that the circulation of water in the unstratified gypsum mass is irregular. It is remarkable also that although both waters issue from gypsum only the upper one is saturated with CaSO-4, the lower one being distinctly below the saturation point. The water from the cap rock at Humble exhibits the same peculiarity, which, together with the presence of sulphide in these waters, may indicate that the sulphate is being reduced to sulphide by hydrocarbons.

General Characteristics of the Waters.

Although the foregoing analyses are too few to give more than a general idea as to the character of the Gulf coast waters, they indicate that these waters are monotonously regular in character and that the chief differences are in concentration rather than in the proportions of individual constituents. There is no such radical change in composition, amounting to a complete reversal in chemical character between the surface and the oil zone as the California waters exhibit, nor apparently any abrupt changes at the horizon of the main oil sands, such as Neal has worked out in the Mid-Continent fields. However, the great salt masses are the controlling features in the Gulf coast fields and the great predominance of sodium chloride in the

waters, overshadowing all minor variations, is to be expected. The concentration of a water is evidently determined chiefly by its proximity to the salt mass, the waters directly above the salt thus varying according to their depth and those on the flanks exhibiting a lateral variation.

The analyses bear out the well known fact that the waters near the salt domes are far more salty than those occurring a short distance away at the same depth, and indicate also that the two classes of waters are entirely different in chemical character. The presence of a dome extending to within a thousand feet or so of the surface could thus be easily ascertained by tests of the shallow waters. It is not so clear, however, just how far vertically the zone of influence of a deeply buried salt mass extends. It is evident that the normal waters increase in concentration with depth and verge toward the salt dome waters in character, and it seems probable that normal water at a depth of several thousand feet, though many miles from a salt dome, would resemble a shallow salt dome water. Until the normal increase in concentration and salt content with depth has been determined it may be impossible to decide in some cases whether a water from a deep well indicates a salt dome below or not, although judging from the analyses here given there should generally be no difficulty.

The marked difference in chemical character between the salt dome brines and the normal waters is not only of practical interest, but has a bearing on broader geologic problems as well. This important difference may be expressed in the reactive properties of the waters by characterizing the brines as secondary saline and the normal waters as primary alkaline; or, if desired, it may be expressed in terms of the ratio of sodium and potassium to chloride. The following table shows the average ratio (by reacting value) in the various Gulf coast waters and in those from a few other localities:

Normal Coastal Plain waters (average Anal. 1-6)	2.33
Shallow waters from eastern Texas (Average 35 Anaylses[1]	2.80
Shallow waters from Lasalle County, southwestern Tex. (average 20 analyses)[2]	2.00
Waters of the Goose Creek field (average Anal. 7-11)	.82
Waters of the Humble field (average Anal. 12-18)	.91
Waters of Damon Mound (average Anal. 19-25)	.94
Sea water	.87
Oil field waters of Augusta, Kans. (average 20 anal.)[3]	.80
Oil field waters of Eldorado, Kans. (average 2 anal.)[3]	.82
Appalachian oil field waters (average 12 anal.)[4]	.69

It will be noted that the average ratio in the normal Coastal Plain waters here discussed is 2.33, whereas in all the salt dome brines it is below unity, though distinctly higher in the Damon Mound waters than in those from Goose Creek. The important point is that although the addition of sodium chloride to a normal Coastal Plain water would cause the ratio to decrease almost to unity, it could not possibly bring it below unity; in other words the salt dome brines are not, as is generally supposed, ordinary shallow Coastal Plain waters that have simply picked up sodium chloride on coming in contact with the salt mass. In order to convert a normal Coastal Plain water into brine it would be necessary to add other chlorides, such as those of calcium or magnesium, but the salt masses are, according to the few analyses on record, remarkably free from these substances. The deeper waters of the Appalachian, Mid-continent, and other regions have, however, a low ratio of sodium to chloride and it is possible that the deep Coastal Plain waters are similarly constituted. Without discussing the reasons for this condition it appears safe to conclude that the salt dome brines are not ordinary shallow waters

[1]Deussen, Alexander, U. S. Geol. Survey Water Supply paper 335, p. 110, 1914.

[2]Deussen, Alexander, and Dole, R. B.: U. S. Geol. Survey Water Supply Paper 375-G, pp. 175-176, 1916.

[3]Neal, R. O.: Am. Inst. Min. Eng., Bull. 1 45, p 1, 1919

[4]Reeves, Frank, Econ. Geol., vol. 12, p. 374, 1917.

but are solutions that have ascended from a considerable depth.

The primeval ocean[1] is supposed to have contained free hydrochloric acid and A. C. Lane regards the high chloride waters as connate or fossil waters that represent the composition of the ocean at the time they were entrapped in the sediments. C. W. Washburne has suggested, however, that they are ordinary waters to which chloride has been added in the form of chlorin gas of plutonic origin. Mills and Wells believe that ascending hydrocarbon gases exert drying influence on ground waters, causing the precipitation of sodium chloride and thus decreasing the Na-Cl ratio.

It is of interest to note that all of the waters here discussed, with the exception of the cap rock waters, contain little, if any, sulphate. Most oil field waters the world over are free from sulphate, a condition which has long been supposed, without definite laboratory evidence, to indicate that sulphates are reduced to sulphides by reaction with hydrocarbons and thus eliminated from the waters. There is little evidence to support this theory in the Gulf coast fields, for since even the normal Coastal Plain waters are practically free from sulphate no particular significance can be attached to the absence of sulphate in the oil field waters. However, the fact that the cap rock waters contain sulphide and are not saturated with sulphate may be an indication that this reaction has taken place, though in the main sulphate is of no practical value in these fields as an index of the horizon of a water.

Minor differences in the proportion of individual constituents do not seem to follow any simple rule and appear to be a feature of the dome rather than of a depth or horizon. Thus the proportion of alkaline earths to alkalines is very similar in all the Damon Mound waters, but the average at Damon is lower than that at Humble, and both are below the average at Goose Creek. The ratio of magnesium to calcium by reacting value ranges irregularly between .08 and .80 in the various waters analyzed, but the average ratio at Damon is lowest and that at Goose Creek highest. Bicarbonates, though present in all the waters, are invariably in very minor proportions. Tests for the rarer elements

[1]Personal communication.

in these waters, now being made, may, however, bring to light variations which the ordinary analyses fail to show. Iodine, for example, is regarded by Professor Mrazec[1] as an indication of water that has been associated with oil, and tests for iodine, as well as for bromide, boron, barium, strontium, etc., may prove of direct economic value. Determination of petroleum constituents, such as naphthenic acids, dissolved in the waters has proved helpful in California and elsewhere and may also be of value in the Gulf coast fields.

One constituent of salt dome waters which, though probably of no value as an index of the horizon of the water, is nevertheless of great economic importance, is potash. It is true that all the analysis here given show a very low content of potassium[1] and that a few analyses of salt dome brines published by Turrentine[2] and some analyses of salt published by Harris[3] give similar results; yet so far as the writer knows no systematic search for potash in the Gulf coast salt domes has been made and the negative character of the results so far obtained does not prove that potash is absent. One's belief in the presence or absence of potash depends in a measure on his theory of the origin of the domes. According to all theories which explain the salt as a precipitate from solution a large proportion of the salt must have remained in solution and escaped, and the portion that escaped would of course include the highly soluble potassium compounds. If this type of theory is accepted the hope of finding much potash must be abandoned. The intrusive theory, however, postulates the ascent of the plastic salt mass under pres-

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[1]In most of these analyses the potassium is reported simply as a trace, but as the analyses were originally expressed by the chemist in grams per hundred grams the term, trace, simply means less than 0.01 gram, which is equivalent to a hundred parts per million.

[2]Turrentine, J. W., The occurrence of potassium salts in the salines of the United States; U. S. Bureau of Soils, Bull. 94, p. 60, 1913.

[3]Harris, G. D., Rock salt in Louisiana; Louisiana Geol. Survey, Bull. 7, p. 16, 1908.

sure, and if this view is correct the salt plugs should contain the same proportion of potassium as the original salt beds of which they are the offshoots. Extensive and systematic core drilling of the European domes, which are believed to have had a tectonic origin, has shown that potassium salts occur chiefly as irregular stringers or lenses in the salt, usually dragged to an inclined or vertical position, and in the writer's opinion whatever potash is found in the Gulf coast salt domes will occur in the same fashion. It is only by core drilling that such deposits are likely to be located, yet a clue to their presence may be obtained through analyses of the salt dome waters, especially of the waters in close proximity to the salt mass.

Value of Water Analyses in Gulf Coast Oil Work

It is believed that the differences in character and concentration exhibited by waters occurring in various positions with regard to the salt domes are sufficiently marked and regular to permit the use of analyses in estimating the position of a water, and probably also in locating deeply buried salt domes. In a field like Goose Creek, for example, where the sands are practically flat-lying, a fairly regular increase in concentration with depth may be expected, and once the character of the water in each sand has been determined it should be possible to ascertain by a simple test the approximate source of the water flooding a well. It may be supposed that similar conditions obtain in such fields as Welsh, Jennings, Edgerly, the shallow Humble field, and probably Sour Lake and Saratoga. In such fields as Humble and Damon Mound, where oil is found in the steeply dipping sands on the flanks of the dome, it will doubtless be more difficult to establish a workable relation between the composition of a water and its horizon, though where the dip is not too steep, as in the deep sand belt at Humble, such a course would seem to be entirely practicable. In the search for new and deeply buried domes analyses of the waters would also seem to be of value, for many wildcat wells are abandoned at moderate depths simply through lack of encouraging indications, and if it could be shown that the deepest water encountered was of such character as to point to a dome below it might be possible to continue drilling until the dome was actually located. A new salt dome of course does not neces-

sarily mean a new oil field yet most, if not all, the Gulf coast oil is associated with domes and the importance of discovering new ones is thoroughly realized.

As all the salt dome waters except those occurring directly in the cap rock appear to be very uniform in chemical character and to differ chiefly in the matter of concentration, it would seem that for ordinary routine work a complete analyses is unnecessary. After a few representative waters from a field have been completely analyzed it should be possible to characterize a water pretty closely by simply determining its concentration. This is most accurately done by evaporating a small portion and weighing the salts direct, but for more rapid work on strong brines the determination of specific gravity by means of a Westphal balance might be preferable, and for still rougher work some form of hydrometer might be used. The Westphal balance, which is small, portable, and not difficult to operate, gives accurate results on waters containing more than 10,000 parts per million, and acceptable results on waters carrying more than 1,000 parts. If more dilute waters are to be examined or if an added criterion is desired in the comparison of brines, the determination of chloride should be of value. Chloride may be easily determined by titrating with standard silver nitrate solution, using potassium chromate as an indicator.[1]. Calcium and magnesium are less easy to determine in strong brines, and in such waters the ordinary soap test is of little value. In the main a fairly accurate gravity test, perhaps supplemented by a chloride determination, furnishes a pretty reliable index of the water, and it is believed that a large number of tests of this type are preferable to a few complete and accurate analyses.

The collection of reliable samples whose analyses may be used as standards for comparison is difficult in most oil fields, but especially so on the Gulf coast. It is usually difficult in a rotary hole to fix precisely the limits of the water and oil sands, especially as these sands vary in thickness and even in position from well to well, and it is therefore not unusual to set a hundred feet

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[1]A description of various rapid field methods of examining waters is given in U. S. Geol. Survey Water Supply Papers 151 and 236.

or more of strainer, which may permit the water from several sands to enter and mingle with the oil. Such mixed samples are undesirable for purposes of comparison and if, in addition, top water is leaking down behind the casing the analysis of the sample may be entirely misleading. In the older fields the waters may have thus mingled to such an extent that water analyses are now of but limited value.[1]

In order to secure samples from definite horizons it is desirable to collect them while the well is being drilled or while a single sand is being tested. In some cases it is possible in this way to collect a suite of several samples from the same well,

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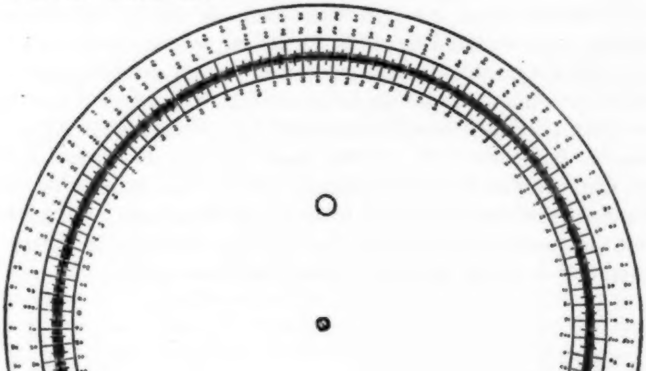
[1]Waters from the first wells sunk in the Bibi-Eibat field, Russia, and analyzed in 1876, showed no sulphate; but in 1906, when water troubles became so serious that an extensive study of the waters pumped with the oil was made, it was found that half of them contained considerable sulphate. This was found to be due to failure to shut off top-water and to the excessive use of Caspian Sea water in drilling. When this changed or "unnatural" distribution of the waters was recognized and worked out, analyses were found to be of great value in locating the source of invading waters. (Goloubjatnikov, op. cit.)

DESIGN FOR LOGMETER

By GEO. E. BURTON, *Oklahoma City, Oklahoma.*

In working with well logs, I have felt the need of some sort of mechanical device that would reduce with accuracy and speed, well log footages to sea level elevations. Other Geologists have expressed the need of such a device. The accompanying sketch designs an instrument which I believe will fill this need. I have called this instrument a *Logmeter.*



Logmeter Fig. 1

The logometer consists of two plates, an outer and an inner plate, the contact of which is a circle. The inner plate is a steel disc, .05 of an inch thick, radius 3.2 inches, the outer upper

edge of which is divided into 1,000 equal parts. These parts are numbered clockwise from 0 to 1,000. The outer plate consists of a steel rim .1 of an inch thick, .6 of an inch wide, attached by four steel arms .05 of an inch thick, 2.4 inches long to a central steel disc .05 of an inch thick, radius .75 of an inch. The inner upper edge of the rim is divided into 1,000 parts numbered counter clockwise and another set from 0 to 1,000, clockwise. The inner plate fits within the outer rim of the outer plate so that the upper surface of both plates are even, and is attached to it at the center by a screw about which the inner plate revolves on the outer plate. A knob .3 of an inch high is attached to the upper surface of the inner plate 1.5 inches off center.

The well log footages are read on the graduated scale on the inner plate and the sea level elevations on the rim of the outer plate.

To reduce well log footages to sea level elevations, set the zero point of the inner plate on the figure which is the elevation of the collar of the well, the footages of which are to be reduced. The number on the outer plate opposite any particular number representing any particular footage on the inner plate will be its sea level elevation. By keeping in mind the number of thousands, well log footages of any depth, the elevation of the collar of the well being given can be reduced to sea level elevations, except the footages of those wells whose collars are below sea level, and these could be reduced if the parts on the inner plate were numbered from 0 to 1,000 clockwise. There are, however, so few wells that start below sea level that it is not practicable to add these extra numbers.

OBSERVATIONS ON THE BEND IN BOUGH NO. 1 IN BROWN COUNTY

BY V. V. WAITE AND J. A. UDDEN, *Austin, Texas.*

This well was drilled by the firm of Bartles and Dumenil in the latter part of 1918. According to the latest reports, work was still in progress (this year) at 2815 feet. The authors have been furnished with a drillers log down to this depth. This log shows that the strata penetrated consist mostly of shales and limestones with some sand, down to 1910 feet. Limestone is reported at intervals not exceeding 250 feet anywhere down to this depth. From this part of the section no samples have been examined. From 1910 feet to 2815 feet the drillers have furnished to the authors samples taken from every screw. The material penetrated below 2278 feet is without any doubt the Ellenburger limestone, and it is evident that the material from 1910 to 2278 feet belongs to the Bend series. This is overlain by dark shale 200 feet in thickness from the upper part of which some limestone is reported. Whether this also belongs to the Bend, it is impossible for us to say; nor can we make any guess as to the correlation of the limestones occurring for the next 200 feet above. The large amount of limestone reported in this interval is greatly at variance with our knowledge of the Strawn formation, as it appears on the Colorado river.

The junior author of this paper visited the locality of this boring in August of last year. The boring was then down to 1916 feet below the surface. Arrangements were made for the securing of samples taken at every screw from 1916 feet and down. These have all been examined, but we will here confine our discussion to the materials representing the Bend, down to 2278 feet, where the drill entered the underlying Ellenburger limestone.

The section studies consists essentially of limestones and shales. These may be grouped into four divisions which we have designated as A, B, C, and D. Within each of these divisions, excepting the division B, alternations from limestone to shale occur. As near as these alterations can be made out from the samples they are all as follows:

	Nature of Material.	Feet below surface. From.	To.
Division A.	Limestone	1910	1928
	Shale	1928	1931

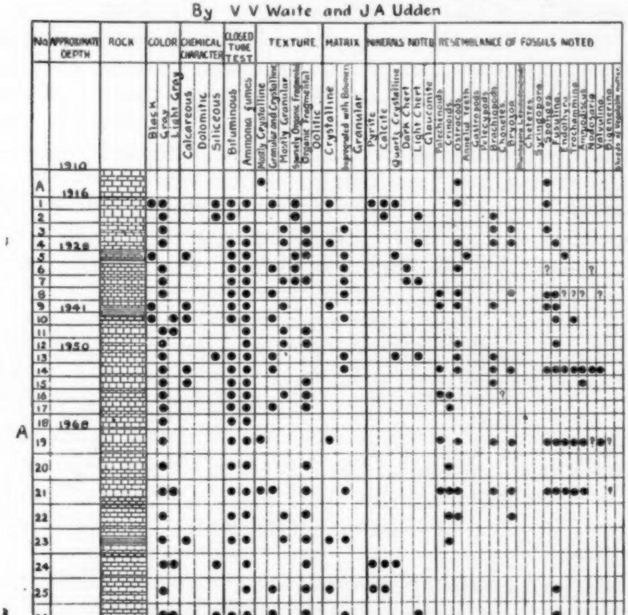
	Limestone	1931	1932
	Shale	1932	1933
	Limestone	1933	1941
	Shale	1941	1943
	Limestone	1943	1992
	Shale	1992	1994
	Limestone	1994	2044
Division B.	Shale	2044	2072
	Limestone	2072	2090
	Shale	2090	2092
	Limestone	2092	2096
	Shale	2096	2097
	Limestone	2097	2098
Division C.	Shale	2098	2102
	Limestone	2102	2104
	Shale	2104	2110
	Limestone	2110	2111
	Shale	2111	2113
	Limestone	2113	2114
	Shale	2114	2156
	Limestone	2156	2158
	Shale	2158	2165
Division D.	Limestone	2165	2167
	Shale	2167	2276
	Chert and dolomitic Limestone	2276	2278
Ellenburger	Dolomitic limestone	2278	2810

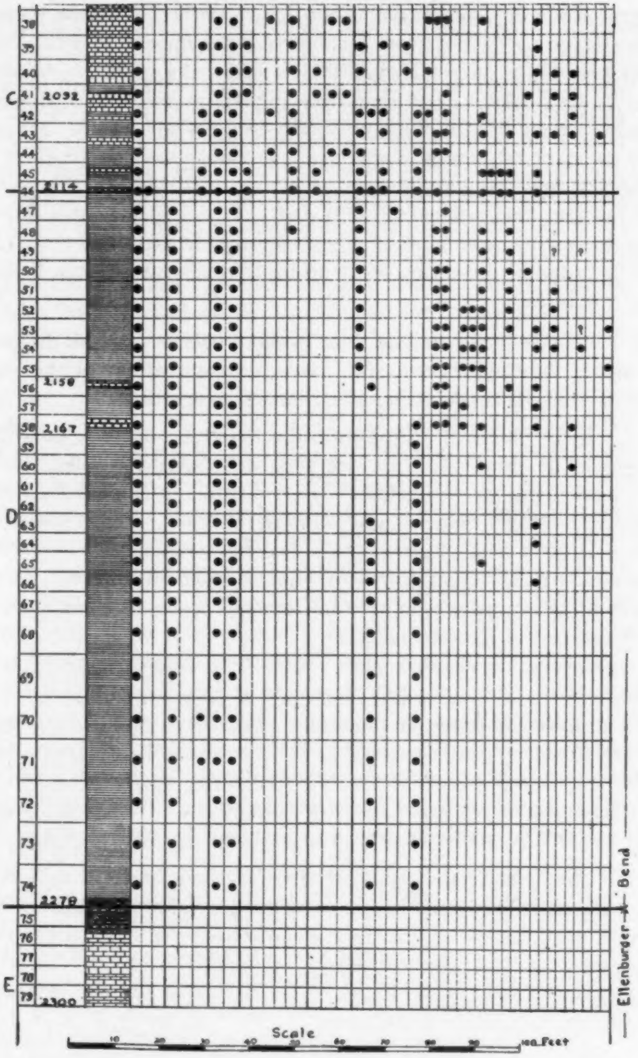
It will be seen that from 1910, 2044 feet the material consisted in the main of limestone with a few thin layers of shale; from 2044 to 2072 feet the section consisted of a single stratum of shale; from 2072 to 2114 feet the section consisted of six alternations from lime to shale, in which the upper half was mostly lime and the lower half mostly shale; from 2114 to 2278 feet, the section was practically all shale, with only two thin layers of limestone in the upper third of the interval. Below this the material penetrated was one continuous limestone, without break, and, as stated before, this is the Ellenburger limestone.

We shall refer to these four parts of the section as A, B, C, and D, taken in order from above downward. We will here present some characteristics of each of these divisions, as made out by examination of the cuttings submitted.

Chart of a part of the Bend strata penetrated in Bartles and Dumenil well, Bough No 1 showing distribution of diagnostic characteristics ascertained by an examination of cuttings

By V V Waite and J A Udden





Division A.

As to color the limestone in this division is mostly neutral

gray when dry, and darker when wet. At three horizons there is a change to lighter gray. These changes appear at 1945-1966; at 1968-1973; and at 1996-2012 feet below the surface. A decidedly dark color in this limestone appears at five levels, three of which occur in immediate proximity to the shaly layers. Most of these dark or almost black layers probably have a thickness of only a few feet, as the one occurring at 1943 feet, the one at 1990 feet, and another at 1994 feet. Two evidently still thinner layers of the same kind of limestone occur at 2010 and 2035 feet. The latter of these two, most probably represents a seam of only a few inches.

The decidedly darker color in these layers is due to the presence of bituminous material. Most of the cuttings of this dark color will sustain a flame when heated to ignition.

In its chemical composition the limestone is fairly pure carbonate of lime. In thin sections it is seen to contain some scattered grains of siliceous sand at 1916, 1955, and 2000 feet. Cherty silicous material was observed at 1920, 1923, 1950, 2010, and at 2020 feet. Pyrite occurs sparingly, mostly in microscopic grains. Fairly clear calcite is almost invariably present, at the depths where pyrite occurs, and crystalline quartz was also observed in the same association. The depth at which these three minerals occur together are: 1916-1919, 1928-1931, 1941-1943, 1950-1964, and 1994-2007 feet. It is an interesting fact that these minerals occur in the strata where sand enters as a small constituent in the limestone. The chert is absent from these layers. These minerals are most frequent in the more porous horizons of the series, no doubt for the reasons that mineralization is favored by relatively free circulation of the ground water.

The volatile materials of the limestone show considerable variation. The bituminous contents are markedly less in the light gray limestone than in the darker layers. The sulphurous contents are least pronounced in the upper third of this member. Ammonia fumes were found to be invariably present in all the samples, but differ in amounts.

The texture of this part of the section is much like that of the limestone in the lower divisions. The rock consist of a mixture of organic fragments in a matrix of granular or crystal-

line calcareous material. We have called the texture of the matrix granular when it consists of fragments that are not clearly bounded by crystalline surfaces, and when these fragments average less than one-twenty-fourth mm. in diameter. Most granular areas in the thin sections that were prepared, consist of particles considerably below the size named. We have designated as crystalline such part of the matrix as consists of clearly crystalline particles that average about one tenth mm. in diameter. Such parts in the thin sections always appear clearer and more transparent than the granular areas in the sections. The two kinds of material that go to make up the matrix are always both present. Even in small fragments one seldom finds the material either all crystalline or all granular. We have attempted to estimate the degree of crystallization the rock has undergone by roughly estimating the areal contents of each kind of these two materials in a hundred thin sections. From such a general comparison, it is found that there is an increase of crystalline material at the levels where the rock is most porous. This preponderance, however, is quite slight. The quantitative relation between the matrix and enclosed organic fragments is also variable. The organic fragments are most abundant in the part of the section between 1923 and 1945 feet, and again from 1953 to 1956, and from 2012 to 2030 feet.

The more frequently identified fossils in this part of the Bend are fragments of crinoid stems and of spines of palechinids. Most of these were observed in thin sections, and could be identified by their texture and form. Palechinid and crinoid stems are most common in the middle part of this limestone. Ostracods are quite common. These mostly have a smooth exterior and are oval in form. Remains of annelids such as their small denticles, are exceedingly infrequent in the entire section. A single instance was noted at a depth of 1928 feet. The brachiopods are represented by small fragments of spines and occasionally by thin scales of ground-up valves. They cannot be said to be frequent. The same is true about bryozoa which occur mostly together with brachiopods. A small Rhombopora was noted at 2022 feet. A Chetetes was abundant at the same depth, where it apparently exists in large masses that have been ground up by the drill. Spicules of sponges are frequently seen in the shale as well as in

the limestone. At some depths they are well preserved, and at other depths they are present in the limestone merely as straight tubes filled with clear crystalline calcite, so as to appear like straight translucent lines in thin sections. In many cases the original siliceous material in these spicules is still present, as has been ascertained by maceration. Fusulina is a common fossil, though not very abundant. Endothyra occurs sparsely in the middle part of the division. Smaller foraminifera, such as Trochammina, Ammodiscus, Nodosaria, and Valvulina, were observed in fully one-third of the samples examined. These appear to occur together, especially at some levels. Thus we find them at 1940, 1955, 1970, 2022, at 2044 feet, and in the lowest five feet of this member of the section.

Division B.

Below the division designated "A", we have a shaly member about 28 feet thick, extending from 2044 to 2072 feet. This shale is very dark, almost black, in color. It is somewhat indurated and does not readily produce mud when washed. It has a small calcareous ingredient and at least a part of this ingredient is present in the form of microscopic rhombohedrons of calcite. The shale contains a small admixture of fine sand. It is pyritiferous and the pyrite is all in minute particles. When heated in a closed tube, strong bituminous fumes and strong ammonia fumes were produced by all the samples. The shale will almost invariably sustain a flame, when heated to ignition. Organic fragments are present, but sparse. The only forms observed were a few crinoid stems, several ostracods, occasionally a sponge spicule, an Endothyra, and in one instance, a Valvulina.

Division C.

The division we have designated as "C", consists of gray limestone and almost black shale, extending from 2012 to 2114 feet below the surface. It has a thickness of 42 feet. The upper half of this member consists mostly of limestone while the lower half consists mostly of black shale. At five levels the limestone contains layers that are almost black from the presence of bitumen. These levels are at 2072, 2082, 2092, 2110 and 2114 feet below the curb of the well. It is noticeable here, as above, that

the darkest limestone is closely associated with the black shale. The shales are calcareous, as in Division B., from the presence of imbedded minute rhombohedral crystals of calcite. Such crystals are also found throughout the limestone. Some siliceous and apparently cherty material is present in the limestone at 2110 feet. A slight ingredient of fine sand occurs both in the shale and in the limestone. The horizon is characterized by the appearance, especially in the shaly member, of rather large, rounded grains of glauconite and small black spherical concretions of pyrite. These concretions vary from one eighth to one fourth mm. in diameter. Some of the Glauconite grains seem to have suffered from oxidation and appear brownish yellow in thin sections. Others are bright green. They vary from one eighth to one fourth mm. in diameter. The presence of much ammonia and of bituminous fumes was noted in practically all the samples examined.

The limestone appearing in this part of the section is fairly like the limestone in Division "A". Less than half of the rock is crystalline and the other half consists of granular material and of organic fragments. The crystalline texture in places shows an arrangement which indicates that crystallization has started from the exterior of organic fragments. In some instances this results in a corona-like jagged crystalline border, surrounding the organic fragments, in other cases, the crystalline material has arranged self in one or two layers of more perfectly formed calcite crystals of somewhat uniform size surrounding the organic fragments. In places these crystals are imperfectly arranged in radiate lines extending out from the organic fragments they surround. The organic ingredient in this member contains fragments of many kinds, among which some tubular structures, possibly representing some foraminifera more than half fill the space in the thin sections. These tubular structures vary somewhat in size, but are slightly less than one fourth mm. in diameter. In one thin section they were seen to be in a collapsed condition. In some of the sections they form almost a felt-work in the matrix. Sometimes the interiors of these tubes and the matrix are quite perfectly crystallized and clear. Structures of this kind were also noted in the lower part of Division "A". The microscopic fauna noted in this section is of the same general character as that seen in Division "A", but it should be especially noted that a Bigenerina was

found to be quite abundant in the shale at 2100 feet and a Syringopora occurs at 2092 feet. This is the highest point at which any Syringopora was noted.

Division D.

The division that we have designated as "D" extends from 2114 feet to 2278 feet below the surface. It consists of black shale with two thin layers of black limestone at 2158 feet and at 2167 feet. It has a small calcerous ingredient, a part of which is in the form of microscopic rhombohedral crystals of calcite. Minute particles of pyrite are sparingly present in all the samples, and dark chert was noted in the upper 10 feet of light-green glauconite were noted. These grains measure between one fourth and one eighth mm. in diameter. Glauconite casts of this division. From 2160 to 2278 feet rounded grains of clear, sponge spicules and some minute indeterminate porus bodies filled with glauconite were noted at about 2105 feet. When heated in closed tube all the samples gave strong fumes of bitumen and ammonia. The shale and limestone will sustain a flame when heated to ignition, due to their bituminous content.

Fossils are quite abundant from 2120 feet to 2170 feet. Crinoid fragments are common between these depths. Ostracods have about the same distribution as the crinoids. Fragments of brachiopods are likewise common between these depths, but from 2170 to 2250 feet they were extremely scarce except for some small ones at from 2135 to 2170 feet. Gastropods were most frequent from 2135 to 2155 feet. Pelecypods were not noted except from 2135 to 2155 feet. A striking feature of the gastropods and pelecypods is their diminutive size. Bryozoa were not noted below 2160 feet. Syringopora was again found to be quite abundant at 2130 feet. Sponge spicules are scattered throughout this division. Fusulina was not noted from a single sample. Such formanifera as Endothyra, Nodosaria and Ammodiscus are present but scarce. Minute fragments of black, fibrous woody-like material were found at two depths, 2145 feet and 2155 feet. It is noticeable that fossil fragments are exceedingly rare from 2170 fee to 2278 feet that this is the interval in which glaruconite is conspicuous.

There is a sharp change from the black shale of the division

"D" to a white chert at the top of the Ellenburger limestone. This chert is oolitic. Below the chert the section consists of white to light straw colored, fine grained and crystalline dolomitic limestone, oolitic at some levels. At 2415 feet this limestone was seen to be made up of rhombic crystals of dolomite of variable sizes from one sixteenth to one fourth mm. in diameter. At about 2500 feet these crystals were found to be more uniform in size and about one fourth mm. in diameter. This rock is really a finely crystalline marble.

Summary of the Characteristics of the Bend.

The Bend shales and limestones are quite unlike similar sediments found higher up in the Anthracolitic section. We may, in summing up, mention some features that we believe can be regarded as characteristic of these sediments.

1. Spicules of sponges are more or less frequent throughout the entire section, in the shales as well as in the limestone, and they are particularly common in the uppermost part of the formation.

2. The limestones have a darker color than most of the later Pennsylvanian limestones.

3. The limestones, as well as the shales are noticeably more indurated than later Pennsylvanian deposits of similar kinds. The shales do not readily disintegrate in water so as to form mud in drilling, or when washed.

4. In its texture the limestone may be characterized as quite fine grained. It has evidently been subjected to what may be called incipient hydrous metamorphism. This metamorphism has resulted in secondary crystallization of the calcareous material, and almost throughout the whole section the limestone in the formation was seen to be affected by this change, so as to contain irregular areas of almost microscopic size filled with crystalline material. These areas are not sharply defined from the rest of the rock, which consists of unaltered granular material with imbedded organic fragments. In the thin sections examined the crystallized material constitutes about 30 per cent of the rock. This ratio is quite constant throughout the formation. It was also found that the quantity of organic fragments is greatest in the lower part of the formation and is smallest in the limestones which are least affected by secondary changes.

5. Two recurrent crystalline peculiarities have been noted by the writers in any other Anthracolitic sediments. One of these is an obscurely radical arrangement of crystalline grains of calcite surrounding centers believed to be represented by obscure organic remains, and in places evidently indicating the outlines of such remains. The other is the occurrence throughout the entire section of microscopic rhombohedral crystals of calcite that lie scattered in the rock. These crystals occur in the shales as well as in the limestones.

6. All of the shale and most of the limestone give strong fumes of ammonia and bitumen when heated in a closed tube. The persistency of this feature is characteristic.

7. Imbedded round grains of glauconite of pale green color are present in the lower third of the section examined.

8. Organic fragments are present in all of the limestones but are most abundant in the limestones in the lower half of the section. The fauna is characterized by the occurrence of small spines of palechinids, spicules of sponges, valves of ostracods, and by a relative scarcity of brachipods, molluscs, and bryozon. Fusulina occurs in the upper half of the section. Endothyra and other small formanifera are not particularly abundant. One of these is believed to be a Bigenerina of somewhat large size. This was seen to be quite abundant at a level slightly above the middle of the section examined (3025 feet). Though our observations are naturally limited to small fragments in every case, we have the decided impression that the Bend fauna is characterized by diminutive forms. Full size forms of the fossils present seem to be infrequent. In the entire lot of seventy-five samples, only one single fragment of a medium sized crinoid stem was noted.

Note:—Depths in feet were given for only a few samples, but all the samples were numbered in consecutive series. The depth of each sample has, therefore, been estimated from the number of samples between each interval of known depths. The depths given were: sample No. 18, 1968 feet; sample No. 40, 2090 feet; sample No. 67, 2208 feet; sample No. 74, 2278 feet; sample No. 79, 2301 feet.

The probable error of the depths assigned to the samples in the accompanying table is not believed to exceed ten feet for any sample.

SOME PHYSICAL PRINCIPLES OF THE ORIGIN OF PETROLEUMS

By Chester W. Washburn, *New York*

Let us use the text for this short discussion: *"Energy, like water, always must run down hill."* By keeping this text in mind one avoids many pit-falls of theory.

The major principle is equally useful: *"Every action is accompanied by an equal and opposite reaction."* As an example of the application of this, one sees that pressure cannot be a direct cause of the origin of oil from organic matter, because in the process of formation, there is a great expansion in volume of the original matter.

Chemical reactions follow those rules as perfectly as the phenomena of physics, of which chemistry is really a branch.

Only in the case of the chemical processes of life, is there any reason to doubt the complete application of physical laws. Loeb and others are rapidly increasing the application of these laws to the life process, and no true scientist feels guilty of an irreligious materialism in expressing the belief that some day all the phenomena of life will be so explained.

The physical mystery of the life-process is this: How can a living plant seemingly work against the normal down-hill course of energy? How can plants decompose water and carbon dioxide and convert them into cellulose and other compounds, which contain what seems to be a surplus of energy? Chlorophyl, or something else in their protoplasm, enables plants to expend enormous force in breaking water and carbon dioxide into elemental components and in assembling the latter in organic molecules. When a plant or animal dies, its parts all lose the power of performing reactions of this kind. The full explanation of that power in living matter remains a mystery of science.

Processes of this kind are called *endothermic* because they absorb heat. Endothermic processes are rare in Nature, outside of living matter. The only other conditions under which they can occur is where there is an increase of temperature, or other changes that facilitate the absorption of heat. Thus, the

formation of the complex silicates (hornblende, mica, feldspar, etc.) in thermal metamorphism of deeply buried sediments, is an endothermic process with reference to the silicates. There certainly are no endothermic processes, other than those of plants and animals, that affect inorganic matter at the earth's surface. Nor is there any known endothermic reaction that takes place in organic matter within the zone of unaltered sediments. From the principles of energy, it is logical to assume that endothermic processes cannot take place in the dead tissues of organisms buried in shallow sediments.

Engler and Hoefer say that the natural dissociation of organic fats and waxes into petroleum is an endothermic process. This statement led me astray for many years. It made their own theory seem impossible, as also all theories of the organic origin of oil under the low temperatures that are available. However, I am now convinced that the dissociation of buried organic matter is not an endothermic process, but is the reverse. It is highly *exothermic*, i. e., it liberates heat. This conclusion opens the way for theories of the dissociation of organic matter into petroleum, under low temperatures.

The endothermic heat stored up in organic matter is liberated when the matter is decomposed or burned. By burning organic matter one obtains more heat than could be furnished merely by the amount of hydrogen, carbon, sulphur, etc., available for combustion. This surplus of energy, or endothermic heat, does not lie in the chemical elements of the organic matter, but is held someway within the valences that bind the parts of molecules. It had its ultimate source in the energy of the medium in which the organism lived. In the case of green plants the stored endothermic energy is thought to be derived from the sun's rays. In animal matter it is probably derived from the oxidation of absorbed vegetal matter in the protoplasm of primitive forms and in the gills and lungs of higher forms.

The way in which energy runs down-hill during geological processes is illustrated perfectly by coal. The amount of endothermic heat is greatest in cellulose and other woody substances, and it decreases progressively with the metamorphism of these through the stages of lignite, sub-bituminous, bituminous and

semibituminous coals to anthracite. Anthracite has lost all its endothermic heat, so far as can be determined. It is doubtless their great content of endothermic heat which renders low-grade coals so liable to spontaneous combustion.

Why does coal lose its endothermic heat in this way? Because energy must run down-hill. A simple conception of the main feature of the process is this. Endothermic compounds are unstable under normal conditions of the outer part of the earth, because they contain an entrapped surplus of energy which has no apparent work to do, other than to separate the parts of the molecules. The endothermic heat may be regarded as a sort of tension working against the internal attractions or bonds of a molecule, like an expansive spring that tends to force the elements apart. It is a potential disrupting force. When a little more energy is added to the disrupting force, as in laboratory distillation, the force exceeds the strength of the bonds and breaks the molecule into its component parts. During geological time the disrupting force of endothermic heat appears to break down the organic molecules of coal, without the help of much external energy, because there is good reason to believe that the regional metamorphism of low-grade coals took place at moderate temperature.

I believe the same process of dissociation takes place in buried fats and waxes, with the production of Petroleum. Although I have not ascertained the amount of endothermic heat in fats and waxes, I believe it must be high, because they are composed of complex molecules that result from an endothermic life process, and because they dissociate under heat with the liberation of the most highly exothermic compounds known, namely water and carbon dioxide, in addition to hydrocarbon oils, which also have positive heats of formation.

If fats and waxes are unstable highly endothermic compounds, like cellulose and other coal-substances, it follows that their dissociation is an exothermic reaction which may take place spontaneously in the course of geological time. This is true of most exothermic reactions, but it is impossible with endothermic reactions. The addition of external heat will accelerate the process and usually is necessary to initiate the process, but it is perfectly logical to assume that any exothermic

process of this kind can give effective results in the course of geological time at much lower temperatures than are required in any laboratory experiment.

The endothermic heat, or disrupting force, is constantly present and is constantly striving to split every organic molecule. A very slight increment of temperature prevailing over long periods of time may be enough to start the molecular disruption. Burial under a few thousand feet of sediments may produce the temperature required, and so may a very slight deformation of the rocks. Deformation raises the temperature through friction on slip-planes and through rock-strain. Lateral pressure and the compacting of sediments through deep burial, must cause an adiabatic increase in the temperature of the compressed gases.

Radio-activity and ultra-violet rays may be other agents that promote the dissociation of fats and waxes into crude-oils, since they accelerate many similar processes in the laboratory. In the treatment of cancer, it appears that the emanations of radium cause the decomposition of tissues which are then absorbed by the system. Workers with radium suffer from sores that appear to result from the decomposition of tissues. That radio-activity affects all the outer part of the earth cannot be doubted. The helium present in the natural gases of Kansas, Oklahoma and Texas probably could not have been concentrated from an atmospheric source. It is most readily explained as the end product of radio-active emanations from the depths of the earth, which have collected in the shales because of the well-known selective absorption of emanations on clay. Therefore it is quite possible that the formation of oil in the Mid-Continent fields may have been started or accelerated by radio-activity in past ages.

An interesting deduction of much importance results from the conclusion that the dissociation of fats and waxes is an exothermic process, namely, that once the process is started in a mass of sediments containing much organic matter, the heat liberated by the process will increase the temperature of the sediments, and will thereby accelerate the process. The liberation of endothermic heat by the splitting of one molecule of organic matter would necessarily raise the temperature of adjacent organic molecules, causing some of the latter to dissociate with

further liberation of heat. The continuation of this process would constantly increase the temperature, as long as the amount of heat liberated from the decomposing organic matter exceeded the radiation. Since shale and other rocks are poor conductors of heat, I believe that the natural dissociation of organic molecules would cause a very material rise in the temperature of any deeply buried stratum that contains much organic matter. The first molecules to break down would be the least stable ones, possibly those containing the most endothermic heat. The last to break down would be the most stable molecules, or those requiring the highest temperature for their disruption. If the temperature never rose to the point required for the disruption of the latter molecules, they probably would remain as part of the asphaltic ingredients of the oil.

Professor O. F. Stafford of the University of Oregon has developed a new process for the distillation of tars from sawdust and other mill refuse of pine-woods. A part of the sawdust is heated in a closed retort, insulated against radiation. When distillation begins, the fire beneath the retort is extinguished, but the decomposition of the wood continues of its own accord, spreading slowly through the retort until all of the tar has distilled off. Except at the beginning, each part of the distillation is carried on by the endothermic heat liberated by the dissociation of molecules in the preceding part of the process.

The temperature is increased not only by the heat liberated by the process of dissociation, but also by the adiabatic heat caused by increased pressure, which results from the liberation of gases. The process of dissociation creates a great increase in volume of the buried organic matter. The fine pores of shale oppose high resistance to migration, causing an increase of pressure on the generating gases and hence an additional increase of temperature, which further accelerates the process of dissociation.

The word *distillation* should be carefully avoided in discussions of the origin of oil. Distillation is a process of vaporization and condensation. It is impossible under low temperatures, even in a vacuum, for any of the heavier elements of oil. From our present conception of former rock temperatures we cannot admit that these ever have been high enough to vaporize any

elements of oil heavier than kerosene. If underground pressures are considered, it is hard to admit even that the kerosene in crude-oil could have passed through a vapor stage in formation. The word "distillation" therefore is misleading in concept. The expression "natural distillation under low temperatures" is an impossible anomaly.

Distillation experiments under high temperatures and pressure by Engler and others, have produced many hydrocarbon mixtures, some of which are essentially identical with crude oils. The application of heat breaks down animal fats, liberating carbon dioxide and water, and splitting the residual parts of the molecules into hydrocarbons of the paraffin and other series. What happens is really an irreversible dissociation of the molecules of fat. Since we have shown reason to believe that the process can occur at moderate temperatures, and since the highest temperatures available for the natural process are some two hundred degrees less than those required for complete vaporization, it is clearly misleading to use the word "distillation."

The more general term "dissociation" covers the ground, and leaves the way open for someone to explain the more precise character of the natural process. The dissociation of fats and waxes into oils, gases and residues is unlike most other thermal dissociations performed in the laboratory, because it is strictly irreversible. Only living organisms could bring the dissociated parts together again. From this irreversibility it is probable that the process does not follow many of the common laws of dissociation. For instance, it is probably not affected by the law of the partial pressure of a dissociated gas. The multiplicity of compounds present also make it seem almost hopeless to seek any balanced relations in the process.

Reasons are given below for believing that crude oils grow heavier with time, and that the crude oils we now know are descended from lighter parent oils. With this exception, it is probable that crude oils largely retain their orifinal characters. Oxidation will create asphalt in paraffin oils that were originally free of asphalt, but this appears to be a process of limited possibilities and local effects. In general it seems probable that provinces of asphalt oil, like Mexico, and of paraffin oil like Pennsylvania, and of olefines, etc., like the Apscheron Peninsula,

always were characterized by oils of the present type. There has been no wholesale change of one type of oil into another. Likewise, I will endeavor to show that large fields of light oils, such as the oils in the Devonian and Carboniferous of Pennsylvania, could not have been derived from heavier oils of lower horizons, such as the Trenton limestone, through any process of filtration through shale. The alteration of oil by filtration appears to be a process of importance only at the place of origin.

The general character of an oil probably is affected by the nature of the organic material from which it is derived, but the principal types of oil can be explained satisfactorily by assuming various physical conditions under which the oil was formed. The experiments of Engler and others show conclusively that the amount of dissociation and the position of splits within the molecules are controlled by temperature and pressure. Conceivably the shifting of the splitting points in organic molecules would explain the origin of any type of hydrocarbon.

When the temperature of distillation was too high, Engler obtained only coke and gases from the fats used. Distillation below 400 degrees gave the best results. In distilling at the more moderate temperatures and low pressures Engler found that the percentage of gas and coke produced was very high, but on increasing the pressure he obtained much less gas and coke and more liquid oil. High pressure and low temperature gave the most oil and the least coke and gases. One concludes from this that the degree of dissociation of fat molecules increases with temperature; also that pressure retards their dissociation and shifts the splits toward the center of the molecules, thereby increasing the amount of intermediate or liquid products. The same condition prevails in cracking heavy oils, and advantage of it is taken in the Burton process, etc. When oils are cracked under low pressures much of the material is lost as permanent gas. Under high pressure there is less gas and more gasoline, indicating that high pressure causes a shift of the splitting point inward toward the centers of the molecules.

These conclusions have manifold application. I will endeavor to apply them only to the origin of asphalt and to the distribution of specific gravities in oils of the Appalachian and other regions.

Hoefer thought that oil becomes lighter with time, because he finds that in general the oil in older strata is lighter than that in younger strata. Comparisons of this kind entirely overlook many important factors, such as the different temperatures and pressure under which the oils were formed, and which I consider of paramount importance.

Oils must become heavier with time rather than lighter, because hydrocarbons are exothermic compounds, and therefore they cannot split into lighter molecules unless the temperature rises above their points of dissociation, which in all cases is above 350 degrees C. Reactions of this kind, i. e., those which absorb heat, cannot proceed spontaneously at low temperatures, as do exothermic reactions, such as the combustion of coal. On the contrary, the splitting of a hydrocarbon molecule absorbs heat, and reduces the temperature of its environment. The process therefore tends to stop itself. An irreversible endothermic reaction, such as the "cracking" of hydrocarbons into lighter products, cannot take place until the fixed "cracking-temperature" is reached. The simple principle of physics that heads this paper, seems to require this conclusion. Hence, the distribution of specific gravities in oils of the Appalachian region, which varies with the degree of metamorphism of neighboring coals, cannot be due to any metamorphism of the oil as suggested by David White. Such metamorphism would be only a cracking or dissociation of the hydrocarbons, a heat-absorbing process, which cannot begin below 350 degrees C. or more.

That the light oils of the southeastern Appalachian region are not the products of the metamorphism of heavier oils is shown by their low content of unsaturated hydrocarbons, which is not greater than the percentage of such compounds in the heavier oils of that province. In fact, the lighter Pennsylvania and West Virginia oils are practically free of unsaturated hydrocarbons. Any process of "cracking" oils necessarily increases the percentage of unsaturated hydrocarbons, unless it is accompanied by some process of hydrogenation. There is no probable natural process or hydrogenation of unsaturated hydrocarbons. Methane is a very stable substance which will not combine with other hydrocarbons, even at high temperatures.

In general, light oils are richer in hydrogen and contain

less unsaturated hydrocarbons than heavy oils, and hence could not have been formed by any metamorphic "cracking" of the latter.

It seems a natural explanation of the distribution of light and heavy oils in the Appalachian region to assign their relative characters to the corresponding relative temperatures of formation. Pennsylvania and West Virginia oils become progressively lighter south-eastward, until finally only gas is found in the sands. The metamorphism of the coal and the folding of the rocks increase in the same direction, i. e., toward the main folds of the Appalachians. If the oil was formed during the deformation of the rocks, it is evident that the temperatures and pressures of formations were higher south-eastward, in the zones of greater strain, friction, and compression. From Engler's experiments we have concluded that higher temperatures of formation mean greater dissociation of the molecules of fats. The higher temperatures of formation near the mountains caused more complete dissociation of the original organic matter and hence there are lighter oils and more gas in that direction.

The opposite condition, relatively low temperatures and low pressures, would produce asphaltic oils. In this case dissociation is incomplete. Only part of the original organic molecules were split off, namely the adventitious radicles containing oxygen, which became water and carbon dioxide, and a small part of the total possible amount of liquid and gaseous hydrocarbons, leaving a relatively large nucleus or residue of carbon-rich material. This carbon-rich residue of the original organic matter is the stuff we call asphalt. From our present point of view, its presence is an indication of the incomplete dissociation of the original organic matter.

Therefore an asphaltic oil is not necessarily younger than a neighboring paraffin oil. Rather it is to be regarded as an incompletely formed oil, which may be either younger or older than the paraffin-base oil. I do not believe that Pennsylvania oils ever could have been asphaltic, because their composition does not indicate an asphaltic ancestry, and because of the difficulty of disposing of the large amount of asphalt which they would have left in the rocks.

Asphalt itself is solid and is not strictly oil. It is regarded

as part of the residue of the organic matter that was being turned into oil. Analyses indicate that many asphaltic oils retain traces of combined oxygen. One may infer from this that the complex asphaltic materials possibly resemble coals to the extent that they may retain endothermic compounds. The latter would tend to break down into oils and gases, leaving carbon residues, which would remain in colloidal suspension with the rest of the asphalt. To the extent that this process tends to destroy some of the asphalt, I am willing to admit that asphaltic oils improve with geological age, but I cannot see how any real hydrocarbon, such as the non-asphaltic portions, can split into lighter products under any probable rock temperatures.

The reverse process, that of making heavier oils by the inter-combination of hydrocarbons, is not only possible but highly probable, because it is a process which liberates energy. The saturated hydro-carbons probably cannot combine. It is known however that the molecules of unsaturated hydrocarbons do combine at low temperatures with other or the same kind of unsaturated molecules. This results in both saturated and unsaturated products of higher specific gravity. This process must be the controlling factor in the prevailing metamorphism of crude oils, which tend to become heavier with time. Two factors accelerate the process, namely, oxidation and catalysis.

Oxidation removes atoms of hydrogen from hydro-carbon molecules and thereby render the latter capable of inter-combination. By passing a stream of hot air through Pennsylvania crude-oil, one can convert it finally into solid asphalt.

Oil, being the best reducing agent in Nature, is always in an oxidizing environment. Wherever it migrates, it meets oxides, sulphates, sulphur or other substances that remove a bit of its hydrogen, causing some of its molecules to combine into heavier molecules. Wherever it is touched by circulating ground-water it is attacked by sulphates, nitrates and other oxidizing agents, which it in turn destroys, with the production of hydrogen sulphide, and free sulphur. It is attacked also by the free sulphur, until the latter is converted into hydrogen sulphide. If it enters a red formation, as may be seen in any oil sand outcropping in the Triassic "Red Beds" of Wyoming, it turns the latter green or gray, by reducing the iron oxides. At the same

time the oil is oxidized and made heavier. Oil in red-beds or in strata containing gypsum always is heavy, as in Egypt, in Patagonia, in Angolas and in the salt domes of Texas and Louisiana.

The rather inert paraffin oils do not suffer much from this condensing process where they are protected by heavy covers of shale, and where they have destroyed all the sulphates in contiguous ground waters, as in Pennsylvania. In cases where sulphates remain in the oil-sand waters, as McCoy has shown in the Eldorado and Augusta fields, Kansas, it is probable that the oils are still being oxidized, and are becoming heavier.

Arnold finds that the oil of California becomes heavier as it migrates from its source. This is to be expected as a general rule, because oils must come in contact with oxidizing agents in every step of migration.

That clay exerts a catalytic influence on crude-oil, promoting the combination of molecules, (possibly connected with a little oxidation), is suggested by the experiments of David T. Day as carried out by Gilpin, Cram and Bransky. In these experiments crude oils were filtered through Fuller's earth to determine the effect of that material in separating fractions of the oil. The lightest fractions penetrated farthest, and progressively heavier fractions lagged successively behind, as did also the fractions rich in unsaturated hydrocarbons. Most of the unsaturated hydrocarbons and heavier fractions clung tenaciously to the Fuller's earth, and could not be removed by water, although a large part were removed by solvents.

The writer came to regard these filtration experiments in a new light after performing the following calculations. The specific gravity and amount of each fraction removed by water was determined by the authors of the experiments. I weighted the various specific gravities of these fractions by their amounts in cubic centimeters, and thereby calculated the specific gravity of a mixture of the recovered hydrocarbons. This was done for every experiment recorded by Gilpin, Cram and Bransky. In all of the hundred or more cases, except one, the result was greater than the specific gravity of the crude-oil used in the experiment. In other words, the recovered hydrocarbons, if mixed together, would make an oil heavier than the crude-oil used in the experiment. The effect would be still more striking if it

were possible to include in the calculations the unrecovered oil that was left in the Fullers earth, because the latter was found to consist of hydrocarbons much heavier than the original crude-oil.

This appears to be a clear case of polymerization and inter-combination of hydrocarbons induced by intimate contact with Fullers earth. Clay probably would have similar catalytic effect. The authors of the experiments did not determine whether any oxidation accompanied the process, nor did they recognize the general increase in specific gravity recorded here.

Filtration through shale therefore would only tend to make oils heavier, if the filtration continued long enough for the lagging heavier fractions to catch up with the faster lighter fractions, as where they stopped in a sand. It would remove the unsaturated hydrocarbons and sulphur compounds because the latter would stick tenaciously to the clay.

I doubt, however, that filtration can have any regional effect of this kind, because it seems impossible for oil to move any distance through the rock-body of shale. All shales probably are moist, and a little water would prevent any extensive migration of oil through the pores of shale. Migration across shale formations probably is limited to fissures.

The phenomena of filtration probably affect oils formed in shale to a limited extent as follows. After oil is formed in shale it moves a few inches or at most a few feet through the massive shale, and is gathered in fine crevices, by the process of capillary concentration, which I have described elsewhere. Through these fine crevices it circulates slowly until it meets a sandstone or other body containing large pores, in which it gathers through the operation of the same process. In moving through the shale pores to the first crevice, the oil probably would leave behind it a large part of its original unsaturated hydrocarbons as well as any suspended colloids, such as asphalt. It would reach the sand in comparatively inert form, that is, it would contain very little unsaturated hydrocarbons, and would therefore be an oil whose molecules would not polymerize or combine readily with each other. For this reason it could last through geological ages without becoming very heavy, except where at-

tacked by oxidizing waters. This is my explanation of the comparatively high grade of shale oils.

That the filtration process is not one of perfect efficiency is indicated by the crude-oils of Baku, Russia, which are rich in unsaturated hydrocarbons, although they appear to have their source in clay-shales.

Likewise Arnold and others have presented good reason to believe that most of the asphaltic oils of California originated in diatomaceous shales. These oils also are rich in unsaturated hydrocarbons and the diatomaceous shales contain much clay, yet the diatomaceous shale commonly does not retain enough organic matter or hydrocarbons to stain it black. In most places these substances must have been removed quite completely from the shale.

It has been suggested that much of the California crude-oil was formed from a waxy or oily substance which diatoms secrete within their bodies. The evidence of the distribution of diatomaceous shales in California is the strongest proof of the vegetal origin of a crude-oil that has been presented. Shaw has given similar reasons for believing that the oil of the Kentucky fields was derived from the Ohio shale (Devonian).

In most fields the relation of oil deposits to fossiliferous marine strata suggest that the oil was formed from animal matter. Traces of plant remains are not abundant in these formations, and most sea plants except diatoms, have little skeletal protection against complete decomposition before burial. Sea-weeds are especially liable to rot completely when they die. Animal fats are more resistant to decomposition.

In the Rocky Mountain region of the United States, there appear to have been two main sources of oil. The first is in the Embar formation and other Permian limestones, which furnish asphaltic oil in Wyoming, and lighter oil that is slightly asphaltic in Southern Utah. Where the oil enters the highly oxidizing environment of the overlying Triassic "Red Beds," it becomes much heavier and more viscous. Where the Permian limestones are absent as in Montana, no oil is found at these horizons.

The high-grade Cretaceous oils of Wyoming appear to have their source in the Mowry shale, of the Benton group and in the

nearly equivalent Greenhorn limestone of the Black Hills region. These rocks are hard siliceous and calcareous shales, which commonly have a cherty or rather a horny appearance on fresh fracture, indicating that they consist largely of the skeletons and spicules of small organisms. Their color is prevailingly dark gray or black, and weathered surfaces are nearly white, showing that the dark stain is organic. They contain traces of oil at nearly all outcrops, and in wells they furnish good "shows" of oil, wherever penetrated, on or off structure.

I have personally verified the fact that every "validation hole" drilled to depths of 15 feet or more in the Mowry shale, shows at least good colors of oil. The oil accumulates mostly in the first overlying sands (Frontier or "Wall-Creek" sands), but a smaller amount rises two thousand feet higher across shale and accumulates in the Shannon sand. Sands above the Shannon have not furnished oil in commercial quantities. Where the Mowry shale and Greenhorn limestone lose their organic character, as in Montana, one finds no indications of oil. These facts suggest that the light oils of Wyoming were formed in the Mowry shale, probably from the microscopic animals whose skeletal remains compose most of the rock.

As in other fields, the oil gets heavier as it migrates from its source, being lightest in the Mowry shale (Plunkett field, near Lander, Wyo.) and heaviest in the Shannon sand. The Wyoming fields also show a regional distribution of specific gravity resembling that of Pennsylvania. The oil in the Frontier sands of the most highly deformed fields (Elk Basin and Grass Creek) is the lightest. The heaviest oil of that horizon is found in the Big Muddy field, which is the least deformed. The deformation of the Salt Creek structure is of an intermediate type, and its oil is likewise intermediate in gravity.

In only one instance, the Lusk or Lance Creek field in eastern Wyoming, has this light paraffin oil migrated downward from the Mowry shales. Here it accumulated in the Dakota sand. Elsewhere the Dakota contains only heavy asphaltic oil that ascended from the Permian limestones, being oxidized and made heavier by its passage through the Red Beds. The oil of the Lance field is very light, resembling that in the Mowry shale of the Plunkett field. It was not made heavier in migration be-

cause it descended only through black shales in the lower Benton where it could not suffer much oxidation, because the lower Benton shales are rich in organic matter which doubtless has destroyed all oxidizing compounds within them. I once thought that these black parts of the lower Benton might be the source of the high-grade Wyoming oil, but fuller knowledge of the situation opposes the idea. The black zones continue northward into the barren areas of Montana. They rarely show any traces of oil, which are so prevalent in the Mowry shale.

That heavy asphaltic oils may be derived in part from buried vegetable matter is indicated by the relation of the California oils to diatomaceous strata. That heavy asphaltic oils may be derived from animal remains is indicated by the apparent relation of the Mexican oils to the Tamasopa limestone of Mexico and to equivalent Middle Cretaceous limestones of Colombia, Venezuela, Western Africa and Madagascar. Most of the Mexican oil has accumulated at the top of the formation in which it probably formed (the Tamasopa limestone). If the oil of Venezuela and Colombia had its source in the Mid-Cretaceous limestone, as seems likely, we must admit that the fractured strata have allowed considerable migration and accumulation at horizons above its source. There is such wide-spread association of asphaltic oil with the Mid-Cretaceous limestones of the regions mentioned, that it seems most plausible to assume that the oil originated in the limestone. The heavy oil in the Trinity sand of Texas, may have migrated downward from the Comanche limestone, and the light oil found at some localities in the Trinitv may have ascended from Paleozoic strata, which probably underlie Madill, Okla., and other localities of light oil in the Trinity.

It is certain that the concentration of oil along the unconformity at the top of the Tamasopa limestone must have occurred after the deposition of the Mendez marls (Eocene). In fact it is improbable that the oil could have existed during Upper Cretaceous time even if it scattered through the Tamasopa limestone. More likely the oil was formed from organic matter in the Tamasopa limestone during the folding of the latter in post-Eocene time. The heat of Tertiary vulcanism also may have aided the conversion of the organic matter into oil.

In Florida the Tertiary and the Lower Cretaceous lime-

stones have the same unconformable relations as in Mexico. Mr. Sellards, recently State Geologist of Florida, informs me that the deep wells drilled in the peninsula, passed through the Vicksburg limestone (Oligocene) into Lower Cretaceous limestone at comparatively shallow depth. A thickness of about 2000 feet of massive Lower Cretaceous limestone was penetrated. No indications of oil were observed. The presence of Mid-Cretaceous strata, corresponding to the upper part of the Tamasopa limestone, has not been determined. The principal fossils are foraminifera identical with species in the Comanche limestones of Texas.

In Angola (Portuguese West Africa) the heavy asphaltic oil has its source in approximately the same horizon, as in Mexico, namely in a marine oolitic limestone of Mid-Cretaceous age. This limestone contains tar or asphalt at every outcrop. It is mostly impure, containing much sand and clay. There is a little shale above it, followed by red-beds of continental origin, in which only very heavy tar and asphalt has been found. Occurrences of oil above the red-beds are comparatively unimportant. As is commonly the case in oolites, the limestone carries a dwarf fauna, consisting in this case of diminutive pelecypods and gastropods, with a few tiny ammonites. Apparently the concentrated water in which the oolite was deposited was not a healthful habitat for molluscs, and kept them from growing to normal size. Protozoans of many varieties were abundant and their remains were entombed in the oolite. It is probable that the same concentration of the water that inhibited the growth of molluscs, promoted the preservation of the soft parts of organisms, such as foraminifera and other protozoa in the accumulating oolite. The relations suggest that this animal matter was altered into the asphaltic oils. At all outcrops the oolite rests on granite and crystalline rocks which are not a possible source. Nor could the oil have originated above the oolite because the overlying "Red Beds" are barren of organic matter. Moreover, the "Red Beds" converts into asphaltan oil which enters them. Precluding the possibility that the oil may have descended from them to the oolite, or through them from the Upper Cretaceous marls. The oil found in protected parts of the oolite is lighter than that found in similar places in the "red beds." There is here a strong argument that the asphaltic oil of the Mid-Cretaceous oolitic

limestone of Western Africa is indigenous to that limestone, and was formed probably from the primitive forms of animal life which largely compose it.

Oil-shales have been considered as possible sources of oil. It is possible that the Eocene oil-shales contain traces of liquid oil, but no traces have been found in the oil shales of eastern Canada, Scotland or New South Wales. The essential part of the oil-shales is a solid material of organic origin which yields liquid hydrocarbons when broken down by heat.

The Canadian and Scotch oil-shales have suffered severe deformation, much more than enough to convert them into crude-oils, if they had been capable of such conversion. I suspect that these shales take a line of metamorphism resembling that of coal, and that they become richer in carbon and harder and denser with the passage of time, as analyses seem to indicate. They do not show any indication of creating crude-oils. Moreover the oils obtained from them by artificial distillation consist too largely of evil-smelling unsaturated hydrocarbons that only remotely resemble natural crude oils. It is quite possible that the Scotch oil-shales were derived largely from materials incapable of natural conversion into oils, just as deeply buried celinlose, from its molecular structure, can split-off only water, methane and carbon dioxide but not oil.

The inference that oil shales of the Scottish type are not probable sources of crude oil, may not apply fully to the somewhat different Eocene oil-shales of Colorado and Utah. The great cliffs of that region expose the oil-shales under conditions that are almost ideal for study, and we may expect important new information from them through the work of Winchester and others.

Summary

In summary, the dissociation of fats and waxes into petroleum is an exothermic process and therefore may continue spontaneously at moderate temperatures. Once started by any cause, the process furnishes heat for its own acceleration.

The original oil was comparatively light, excepting varieties rich in asphalt. Crude oils generally have developed into heavier

forms by the polymerization and intercombination of molecules aided by oxidation and by the catalytic influence of clay. All crude-oils become heavier in the course of time, but at different rates, depending on the amount of unsaturated hydrocarbons and on the amount of protection against oxidation.

The main difference in oils may be explained as the result of differences in the physical condition of the place where the formation of the oil occurred, especially important being the differences in temperature and pressure. Filtration through clay is of minor importance, after the first migration of the particles of oil from the spots where they originate.

Asphalt is regarded as representing mainly the residual nuclei of the organic molecules from which oils and gases have been dissociated. Thus it marks an uncompleted stage in the formation of oil. However, it is not possible for an asphaltic oil ever to be converted naturally into a paraffin oil.

NOTES ON THE STRATIGRAPHY OF PANAMA AND COSTA RICA

By Donald F. MacDonald *and others*.

Introductory

Data of the geology of Panama and Costa Rica were collected during 1917 and 1918 by the geologic staff of more than a dozen members who worked under the writer's direction. Previous to 1917, the writer was more or less familiar with the general geologic conditions of these countries and especially with the geology of the Canal Zone.

The facts here presented are a mere outline of the stratigraphic conditions observed. In their preparation, the writer is probably more indebted to Mr. A. A. Olsson, formerly of the Paleontological Department of the Cornell University, and Dr. Henry Hinds, formerly of the U. S. Geological Survey, both of whom were members of the expedition, than to the other members.

The Pre-Tertiary Rocks

Certain highly tilted and somewhat metamorphosed beds in the central mountain areas of Panama and Costa Rica are thought to be of Pre-Tertiary age. However, they contain no fossils, so far as known, so their age relations are somewhat indefinite.

The Eocene Period

Beds of undoubted Eocene age were noted in the Tonosi basin of Los Santos Province. They consist of sandstones and shales, and are locally quite fossiliferous. Among other forms,

they contain the characteristic Eocene index fossils, *Venericardia planiscosta* and the nautiloid *Enclimatoceras.*

The Oligocene Period

During Oligocene time sedimentation was going on over much of the present land mass of Panama and Costa Rica, and these conditions prevailed throughout most of the lower, middle and upper Oligocene.

The Lower Oligocene Formations

Very considerable disposition of limestones occurred during lower Oligocene time both in Panama and Costa Rica. However, beds of shale, sandstone and conglomerates were also laid down between the limestone beds.

In the Province of Bocas del Toro, on the Atlantic coast of Panama, and also extending into Costa Rica, the Lower Oligocene succession is as follows:

Tigre Limestone
Watsi and Mona shales
Sensori Agglomerate and limestone

Of the above, the Sensori agglomerate and limestone consists of agglomerate beds cemented by limy material. Locally, it grades into limestone. That the more limy facies of this formation is of marine origin is shown by the presence of fragments of poorly preserved pectens and a considerable number of Lepidocyclina foraminifera.

The shale series overlying the Sensori agglomerate and limestone consists mostly of fine-grained dark gray argillaceous beds which are somewhat sandy.

The Tigre limestone was locally separated into the Echinoid and the Oyster members. Limestones of equivalent age are rather widespread in Panama and Costa Rica. These limestones are generally characterized by Orbitoides and in places they have a somewhat sandy facies.

On the Pacific the lower Oligocene beds are limestones, sandstones and some conglomerates. The limestones are quite fossiliferous with Lepidocyclina and algal remains fairly plentiful. Locally, these limestones are represented by limy conglomer-

itic sandstones that contain Lepidocyclina and large ponderous oysters.

The upper part of the Bohio conglomerate of the Canal Zone is of the lower Oligocene age.

The Middle and Upper Oligocene Formations

During middle and upper Oligocene time, limy sandstones, sandstones, thin bedded shales and limestones were laid down. Of the middle Oligocene formations, the Culebra beds show much carbonaceous remains, among their thin bedded shales. Locally, they contain some bituminous material and a little natural gas. It is significant that shales of practically equivalent age give seepages both on the Atlantic and on the Pacific coasts. Locally, in the Canal Zone, the Emperador limestone (upper Oligocene) unconformably overlies the Culebra shales. In another area the Cucaracha formation (the land deposited massive clay shale, that gave most of the slides in Culebra Cut) also overlies with some unconformity, the Culebra beds. In other parts of Panama the equivalents of the Culebra beds were found over a very large area, where they consist of black carbonaceous formaniniferal shales with limestones, sandy limestones and sandstones in the lower third of the section. These beds attain an estimated maximum thickness of 3,000 feet.

The Miocene Period

The chief formation of Miocene age is the Gatun. It is a fine-grained soft argillaceous shale with some sandy beds, and some conglomerate in its lower part. The formation is marine, is highly fossiliferous and locally attains a maximum thickness of nearly 3,000 feet. It is found on both the Atlantic and on the Pacific sides, showing that the Isthmian land was pretty well submerged during Miocene time. The Gatun beds are somewhat unconformable on the Oligocene formations.

The Toro formation overlies the Gatun beds with some unconformity. It consists of a coarse massive sandstone which shows some cross-bedding. Locally, the basal part of the Toro formation consists of limestone and limy sandstone beds. In the vicinity of Toro Point near Colon, the limestone is a coquina composed mostly of shell fragments. It is not quite settled yet

whether the Toro formation is Pliocene, as was formerly believed, or upper Miocene, as it is now thought to be. Sandy beds equivalent to the upper Gatun or the Toro formation carry considerable lignite in the Atlantic areas of Panama and Costa Rica near the boundary between the two countries. A collection of fossils made by the writer in 1912 from the soft clayey shales of Moine Hill, three miles out from Port Limon, Costa Rica, was determined to be of Miocene age.

The Pliocene Period

Coral limestones of Pliocene or later age locally fringe the Atlantic Coast of Panama and Costa Rica.

In Limon there is a street cut through a small hill giving a good outcrop of coarse, massive, limy fossiliferous sandstone of Pliocene age.

ESSENTIAL FACTORS IN THE VALUATION OF OIL PROPERTIES*

By Carl H. Beal

Introduction.

The most important factors that should be given consideration in the valuation of oil land are (1) the amount of oil the property will produce; (2) the amount of money this oil will bring (based upon the future prices of oil); (3) development and production costs; (4) the rate of interest on the investment; (5) the retirement or amortization of invested capital; and (6) the salvage or "scrap" value of the equipment when the property is exhausted.

These essential factors are of varying importance, and some of them may not enter all valuation problems, but most of them should be given consideration in any valuation even though only a rough estimate of the value of the property is desired.

The value of a property may be changed over-night by the completion of important test wells, by the sudden flooding, or by a change in the price of oil. The best a petroleum engineer can give is the value of the property under the conditions existing at the time the appraisal is made with a fair forecast of future action of the wells and the price of oil.

Our knowledge on the procedure to be followed in valuations is extremely limited as there is very little published information on the subject, and it becomes necessary in studying such problems to form comparisons with the factors involved in the valuation of mines or of timber land—the closest parallels. One of the reasons for the lack of substantial progress in oil land valuation methods has been owing to the necessity of making an estimate of the future production of the oil property to be valued. Oil men and accountants have not generally conceded that such estimates could be made with any degree of accuracy. It has been shown, however, in several recent publications that with certain data

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available reasonably close estimates can be made. The accuracy of an appraisal depends chiefly upon the accuracy of the estimates of future production and of the future price of oil. The accuracy of the former is sometimes necessarily based on geological inferences. Geology is not an exact science and geological data in connection with oil production cannot always be mathematically evaluated.

The Future Oil (or Expectation)

In considering the factor of future oil, there are two related questions that must be answered; (1) how much oil will the property produce, and (2) at what rate will the oil be produced? If we can determine the future *annual* production of an oil property, we may easily determine the total future production by addition, so we will consider only the question of rate of future oil production.

A satisfactory answer to this question is the keynote to the whole valuation; for, although our work is by no means complete after the question has been disposed of, with a trustworthy estimate of the future annual production completed, the work of determining the value of the property is greatly simplified. For upon the yearly output of oil depends the yearly gross income. From the gross income the annual net return is computed, each year's return being considered in the light of profit available at a future date; the present value of these deferred profits is then determined by discounting them at a rate of interest compatible with the risk involved.

No uniform yearly revenue can usually be expected from an oil property, for the annual output, and thus the annual income depends upon the rate of production. Only under exceptional conditions can a steady oil production be maintained for long unless the property is old and production well settled. The future annual oil output hinges upon the rapidity with which new wells are drilled and upon the rate of production of the individual wells, which with very few exceptions, always declines.

The Rate at Which the Oil Will Be Obtained.

The rate of production of the wells will affect not only the rate of output of the old wells, but also will regulate that of the wells to be drilled. Furthermore, the decline in the initial output

must be considered; the longer the development of the proved acreage is deferred, the less will be its ultimate production, for, under usual conditions, the wells on the drilled acreage cause a decrease in gas pressure over the undrilled acreage which results in decreased initial production of the wells eventually to be drilled there. The rate at which oil wells will produce is the resultant of many complex factors which will not be discussed in this short paper. For more information on this and kindred subjects, the reader is referred to a bulletin by the author, just issued by the U. S. Bureau of Mines.[1]

The most trustworthy method of determining the rate of production of the wells of a group is to prepare a production curve which will give the average yearly output of wells of different initial yearly output. It is necessary to determine this for wells of different initial production, because wells of different output decline in production at different rates—other factors being equal.

The Drilling Programs.

The rate of the production of the property depends not only upon the rate at which the individual wells will produce oil but also upon the rapidity with which new wells are added to the producing list. This depends upon the drilling program. The valuation should not be attempted until a drilling program is decided upon.

Before a drilling program can be decided upon it is necessary to determine the amount of land that certainly will support commercially productive wells, for only the drilled acreage and undrilled proved acreage should be valued. Other land under which the existence of oil is not certain has a certain speculative value that varies with the uncertainty of obtaining oil in commercial quantities. These tracts, if included in the valuation, may be valued separately.

A certain gamble is attached to investing in land of this status and the investor—not the engineer—should decide whether or not the former should take the risk. The magnitude of the risk is determined by the engineer. All that should be told is: the land

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[1]Beal, Carl H.—The decline and ultimate production of oil wells with notes on the valuation of oil properties: Bulletin 177, U. S. Bureau of Mines, 1919.

is worth so much if it eventually is placed in the proved class. The chances of its becoming proved land, based on geological and other evidence, should then be set forth.

The engineer's estimate being restricted thus to proven oil land, he should compute the value of the output of the property based on a drilling program that will bring the maximum return in profits to the investor. It is true that a variation in the drilling program sometimes will greatly reduce the profits eventually gained from a property, but there can be only one maximum value and this is the one to be determined.

Classification of the Land to Be Valued.

Before the future annual production can be estimated it is necessary to classify the land to be valued, to determine the amount of acreage that will support new wells. For this purpose the land is first divided into (A) Drilled and (B) Undrilled. These two classes of acreage must be valued separately.

Estimating the future production of the old wells usually is not difficult, if production curves are available. Our greatest difficulty lies in making estimates of the probable future production of the proved undrilled acreage. Here we must be guided by underground geologic conditions and by what the new wells probably will produce by comparing the conditions under which they are to produce with the conditions under which the nearby old wells are producing.

The undrilled oil land may usually be divided into the following four general classes:

(1) Proved acreage,
(2) Probable acreage,
(3) Prospective acreage,
(4) Commercially nonproductive acreage

Some engineers use much more detailed classifications. These, the writer believes incompatible with the uncertainty of underground conditions.

Proved acreage should include that in which drilling involves practically no risk. The following definition is proposed, which has been modified from that given by R. P. McLaughlin.[1]

[1]McLaughlin, R. P.—Petroleum Industry of California, Bulletin 69, California State Mining Bureau, p. 13, 1914.

"Proved oil land is that which has been shown by finished wells supplemented by geologic data, to be such that other wells drilled thereon are practically certain to be commercial producers."

Probable Oil Land includes those areas generally adjacent to producing oil and gas wells where the existence of oil is not proved, but where geologic evidence indicates a good chance of obtaining oil in commercial quantities.

Prospective Oil Land includes those areas usually not adjacent to producing oil and gas wells, where the existence of oil is not proved, but where geologic data justifies drilling a test well.

Land in this class is distinguished from the probable oil land by the greater uncertainty of obtaining oil owing usually to its location some distance from producing oil and gas wells.

Commercially Nonproductive Oil Land is that on which commercially productive wells cannot be drilled at present. The existence of oil under the areas of this class may be proved, probable or prospective.

Exceptions undoubtedly will be found in every class. For instance, under some conditions, a person may feel warranted to place land in the probable class when it is favorably located geologically even though it is several miles from producing wells, for the reason that the occurrence of oil and gas with relation to certain geologic structures in that region may be so certain as to make the chance of not obtaining *some* oil very small.

Furthermore, the classification of land may change rapidly, owing to the drilling of new wells, damage by water, or change in price. For example, an area that may be rated as commercially nonproductive may become commercially productive and proved with an increase in the price of oil.

The Future Price of Oil.

The accuracy of any valuation depends upon the price that is to be received for the oil, for upon it depends the net profit per barrel of oil marketed. A small variation in the price of oil may mean the difference between gain or loss. In fact, since the working out of new and more trustworthy methods for more accurately estimating future oil production, the estimation of the future price has become one of the most uncertain elements to be contended with in oil land valuations.

The engineer, to make sound predictions as to the probable price of oil, even during the immediate future, must possess a broad knowledge of the petroleum situation as regards supply and demand. Either prices will be allowed to adjust themselves in accordance with the law of supply and demand, or they will be manipulated by monopolies or controlled by the Federal Government. If manipulation or government control exist, or, if there is a strong probability of their coming into existence, the engineer should be guided accordingly. Otherwise, the question of price must be answered solely by the domestic and foreign oil situation.

The past range of prices has often been great, but the future probably will never see such low prices of oil. The market is now more stable because the demand for the commodities made of petroleum is greater and new oil fields are much more scarce and more costly to develop.

The reason for the great demand for oil is primarily because of the great demand for one of its products—gasoline. The great demand for gasoline is created by the phenominal development of the internal combustion engine. This development is probably, by no means, completed, as the airplane and larger numbers of automobiles promise to add greatly to our demand for gasoline. The adoption of oil as fuel by the great navies of the world and the development and adoption of the Diesel engine have already greatly increased our demand for the heavier products of petroleum; very likely the future demand for oil and its products will not decrease.

The upward limit of prices are set by the cost of importing oil and the cost of developing a supply of oil from our oil shales, of which we have tremendous deposits within our own boundaries. By considering the status of the industry at the present time and these two limiting factors in the upward range of prices, the engineer should be able to make reasonably sound estimates of the price of oil for the next few years.

Some engineers find it advisable to use the present prices as a basis of estimating the value of the property or to determine the value of the property at several different prices of oil, and thus allow the investor to select the one which in his judgment will best meet future conditions.

The Cost of Production and Development.

In determining the future net receipts from each barrel of oil, the cost of producing the oil must be subtracted from the gross income, or selling price. For the purpose of estimating future production costs, including drilling charges, tankage, and, in fact, every charge that contributes to the final total cost of production, the appraiser should refer to trustworthy statistics and should be able to interpret these statistics in terms of probable future conditions. This again requires not only a broad knowledge of the oil industry but also detailed knowledge of costs in the locality where the property is situated.

Interest on the Investment.

The proper rate of interest to be received from an investment must be such that capital will be attracted to the enterprise. If the risk attached to the investment is great, the rate of interest on the money invested must be high or investors cannot be found. The returns from oil investments are always speculative to some degree, so the interest demanded on such investments is usually high. So if there is no risk the investor can afford to invest his money at the same rate if he put it in the savings bank at 4 per cent.

The basis of value in oil lands is net income. The net income for each future year of the productive life of the oil property must be estimated and these future values compared with their real values at the present moment by reducing them to present values at a given rate of interest. This is discount and is the reverse of compound interest, the factor used in the reduction of future values to present values being called the discount factor, which is a very important element in oil land valuation. By the reverse of discount, or compound interest, the future value of a present income may be determined.

Present value of a future income may be defined as that sum, which when placed at interest at a stated per cent will equal the income at the date when it is to be realized. Thus, the longer the deferment of an income the less it is worth at the present time, and for this reason one can afford to pay more for income to be obtained from the oil from a well drilled now than for the

same well drilled a year hence, providing the price of oil remains constant and equal amounts of oil are produced. Furthermore, the longer drilling is postponed the less the net proceeds from the wells are worth to a prospective purchaser at the present time. Other things being equal a property should be drilled as quickly as possible, if the maximum income is to be derived from it. This may not be best from the standpoint of the public, and, if generally practiced by oil producers, would eventually work to their advantage.

The interest required on the investment must be high because risk is attached to the venture. Some engineers consider that the discount used in reducing future income to present value, however, should not be compounded for the reason that to compound a certain present sum to determine its future value means the first year to determine the interest on the principal and thereafter to compute yearly the interest on the principal and accumulated interest earnings. The rate used is a high rate because the capital, or principal is being risked. This rate should not be applied to the accumulated interest earnings, however, because these are not risked capital. They are earnings and should be considered as such. Discount is the reverse of compound interest so that the present value of a future sum will be greater than indicated by the present value tables.

The computed maximum value of the property may be considerably less than what actually could be paid for the property for the reason that as the returns on the investment are realized they may be reinvested in gilt edge securities at an accumulative rate of interest.

The Amortization of the Investment.

In investing in an exhaustable resource, the investor expects not only the return of a certain interest on the investment, but also the return of the principal by the time the resource is exhausted. This is called amortization, or the retirement of capital and may be effected by a sinking fund into which annual contributions are made. The sinking fund may be placed at interest, so that the sum of the annual contributions may not be required to equal the total original capital.

Although sinking funds may not be established, nevertheless some attempt must be made to return capital uniformly and just-

ly, where it is possible to estimate the amount of oil recoverable and the hazard of the investment is not too great to make such calculations useless.

A method often practiced by Oil Companies to determine the rate of retiring the capital invested in both physical property and in the resource is called the "settled production method," and consists of applying a unit value per barrel of settled daily production. The value of the property at any time is the daily production multiplied by the unit value. The difference in the value determined at any two periods is the depreciation or appreciation according to whether the value has gone down or up.

A modification of this method for the purpose of determining the depletion deduction in connection with the computing of taxable income, is called the "reduction in flow method." The method has been authorized in the past by the Treasury Department, but obviously is unfair when it is remembered that the basis of the method depends upon a reduction in the output of an oil property from the existing wells only. No depletion is allowed, and, therefore, no capital retired unless production is decreasing. If production decreases 5 per cent during the taxable year, 5 per cent of the capital invested is retired. During the next year if the decrease is 10 per cent, that percentage of the unretired capital is "written off." As a general rule, the output of an oil property increases for a few months, at least, while drilling of new wells is in progress, and in some fields, production may increase for several years. Still by use of this method no capital can be retired till the production of the tract begins to decrease. Now, production of oil means depletion of its recoverable content and every barrel of oil taken from a property exhausts it just that much more, and brings it just that much nearer the end of its life. To retire no capital while production is largest and then when production begins to decline, to retire large amounts against a decreasing income not only is inequitable to the oil operator but places the whole enterprise in jeopardy by deferring the amortization to a period when the field is rapidly approaching exhaustion and too late to cover the return of capital.

The producer has made a definite investment in each barrel of recoverable oil. If he can estimate the amount of recoverable

oil, he can easily determine the cost per barrel. For every barrel of oil produced, he should retire an amount of capital equal to the original investment in that barrel of oil. This is called the "unit cost method," by which a fixed charge per barrel of oil produced, based on quantity, is assessed. It is sound in principle, not difficult of application, and has been adopted by the Treasury Department in the determination of the depletion deduction in connection with the administration of the income and excess profits tax laws. This undoubtedly is the fairest and most equitable way of amortization of an investment in mineral properties. The method is suggested in several publications on mine accounting,[1] so has the added weight of precedence.

The basis of this method is to determine the total capital invested in the oil and then divide the estimated recoverable oil into the capital invested. The result is the unit cost. For instance, if the sum of $1,000,000 is invested in the oil under a property, estimated to produce ultimately 10,000,000 barrels of oil, the unit cost per barrel is 10 cents. The producer has paid this sum for each barrel of oil under the property. Now, if he sells each barrel of oil for $1.50, his net income for each barrel will be determined by deducting all charges from $1.50. Suppose all charges, excepting unit cost, amount to 40 cents per barrel; his net income is, therefore, $1.00.

Estimates of future production may be revised each year and a new "unit cost" obtained by dividing the unretired capital by the remaining recoverable oil. The amount of capital to retire during that year on account of depletion will be the unit cost multiplied by the production.

Many oil companies have adopted this system primarily because by its use they are enabled not only to determine the depletion deduction equitable and justly, but also because they are enabled to retire the capital investment at the same rate at which the oil is produced. The only unknown factor in the determination of unit cost is the amount of recoverable oil and this can be

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[1]Hobart, F.—The Economics of Mining, by T. A. Rickard and others; Page 223, 1905.

estimated with a reasonable degree of certainty by the use of methods outlined by Lewis[1] and the author.

The depreciation refers to the wear and tear on physical property and capital invested in it must be retired in addition to the capital invested in the exhaustible resource. The methods of retiring such capital will not be discussed in this paper. The amount retired should be equal to the capital invested minus the salvage or "scrap" value of the equipment.

Salvage Value of the Equipment.

When the oil is exhausted, a certain amount of physical property will be on hand. The investment of this physical property should have been completely amortized, with no investment remaining excepting that which can be realized from the disposal of the equipment. This sum is called the salvage or "scrap" value of the equipment. Ordinarily this "junk" value is not great at the exhaustion of the oil. Furthermore, the proceeds derived from the sale of the "junk" must be discontinued to the time of the valuation at a certain rate of interest. Usually the property will have a life of more than 20 years, and the present value of the junk, even at a comparatively low rate of interest, is rather small when compared with other sources of income that must be present before the investment is a good one. Occasionally the expenses in connection with the abandonment of the property, such as properly plugging the wells, will cost as much or more than the present value of the junk, so that this item in oil land valuation is ordinarily not important.

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[1]Lewis, J. O. and Beal, Carl H., some new methods of estimating the future production of oil wells. Amer. Inst. Minl., Eng. Bull. 134, Feb. 1918.

Beal, Carl H. The Decline and Ultimate Production of Oil Wells, with notes on the valuation of Oil properties. U. S. Bureau of Mines, Bull. 177, 1919.

THE PRINCIPLES OF NATURAL GAS LAND VALUATION*

By Eugene Wesley Shaw, *Washington, D. C.*

General Nature of Basis of Gas Valuation

The true value of a natural gas property depends on its earning power. It differs from the value of certain commodities including gas itself, the value of which depends largely on the capital that has been invested in them. Since future earnings can not be determined with precision, the value of a gas property, as ordinarily established, is an estimate and such estimates are made with varying degrees of care. The price at which a gas property will be transferred from a willing seller to a willing buyer depends in part also on psychologic considerations as the buyer and seller, one or both, may not be willing but instead may be acting under stress of circumstances. For these reasons gas properties are often transferred at prices which differ more or less widely from the true value. Good management requires that this difference be reduced to the lowest point attainable. The buyer should, and naturally does, take more or less care that he pays no more than full value and the seller that he receives no less. The buyer or seller who does not carefully estimate values is likely to fail and that is bad both for him and for the community.

The market value of a gas property is not only indeterminate; it is not even fixed. The best approximation as to its value varies continually. Also its value to one person is not the same as its value to another. If it did not at least seem different to different persons there would be few sales. Even the true or theoretical value is not fixed or definite but varies with the quality of the management and other factors which can be modified.

The earning power of a gas property as ordinarily established is the difference between an estimate of future income and an estimate of future costs, both estimates involving periods of time and, therefore, interest charges. It is independent of the amount that has already been spent except as (1) equipment on

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hand that is usable on other properties, (2) real estate, and (3) information resulting from testing, surveying, trials at court, etc., have, like the gas, a market value or affect market values. It often happens that it matters little whether $10,000 or $100,000 has been put into the property both its true value and its selling price may be anything between or even more or less.

At the same time the extent and quality of the improvements as they stand today—the number of wells, the degree of success attained in casing and packing, the usefulness of pipe lines, compressors, gasoline, and carbon plants, franchises and even going condition—do constitute important factors affecting future income and expense and on the whole the values of gas properties depart less widely from invested capital less past income than do the values of oil and some other mineral properties.

A remarkably large number of partly developed gas leases seem to change hands at about the cost of development to date. The price of a gas well, particularly one several miles from a pipe line is commonly just a little more than it cost to get the lease and drill and equip the well. Such a price is evidently controlled not alone by prospective profits of operation but in part by antecedent cost for it is rare that a test affects the prospective returns just to the extent of invested capital and expenses to date. The price indicates that the seller is satisfied if he gets his money out with a small margin of profit—often he had hope of getting oil—and that the prospective returns are not so great as to bring competing bidders with offers far in excess of the market value before the discovery. It indicates that the prospects of large profits from operation are not such as to entice much capital from other channels and in this respect the contrast with oil properties is noteworthy.

Comparison with Oil Land Valuation

A comparison of the basis of value of an oil property with that of a gas property is instructive in several respects. Many of our gas wells were drilled in the hope of finding oil. Had it been otherwise—had gas and oil been found in separate regions—we should have had, with the same prices, less gas on tap, although the supply still remaining in the ground would have been greater because of reduced consumption and wastage. However, prices would no doubt be higher.

Many gas wells are kept in an idle state while developments are awaited; often the owner can not use the gas and does not wish to sell the property until he determines whether or not there is oil on some other part of it.

It is interesting further to compare oil and gas acreage as to gross income per acre and per well and as to the recoverable heat units per acre. If you ask a man in the street who has some knowledge of oil and gas how many times as much he would give for a square mile of average oil land than for a similar area of average gas land he may give some figure between two and twenty. As a matter of fact the gross returns from an average square mile of oil territory seem to be between 100 and 400 times as much as from a similar area of average gas territory, and the difference in net income is of even greater magnitude. The true value is roughly proportional to net income though differing somewhat because of the different average rate of production.

Gas wells are, of course, spaced farther apart than oil wells and the difference in gross income per well is not so great as the difference per square mile. The average oil well apparently returns, at the well mouth, between twenty-five and seventy-five times as much ultimately as the average gas well.

The difference in heat units per acre between oil and gas is still lower—the ratio being something like 20 or 30 to one. It is lower than the cash value difference because the barrel of average crude is worth more for other purposes than for heat production —it is more valuable than a barrel of fuel oil.

The comparisons are somewhat difficult and of unsatisfactory exactness because the elements—"average square mile of oil territory" and "average square mile of gas territory" are unknown and indeterminate. But a sufficiently close approximation can be made to make it evident that the oil bearing lands of the country are worth more than a hundred times as much per acre as the gas bearing lands and the difference in gross returns is of similar magnitude. This is reflected more or less fully by the relative size of bonuses on oil lands and by appraised values.

On the other hand the difference in earning power would not be so great if oil and gas were found in different kinds of regions—if oil were obtained only by drilling for oil alone and gas only by drilling for gas alone. Mineral deposits must pay

much of the costs of prospecting or new deposits will not be opened up. They would have to pay all the costs and perhaps more were it not for the fact (1) that certain very human beings include the joy of taking a chance among the pleasures for which they are willing to pay, and (2) for optimism or the fact that to certain ones—commonly the same ones who take chances—everything looks good until it is proven to be bad, and (3) at auction sales something akin to mob spirit sometimes carries prices to unreasonably high points.

The fact that prospecting for gas involves about the same sort of an operation as prospecting for oil and in the same sort of country and the fact that oil is more of a precious mineral than gas, makes oil pay a large part of the costs of prospecting for both and leaves gas—or as always the ultimate consumer—to bear only development costs. Otherwise gas might not be so much less precious.

Significant Fact Concerning the Property

Although the appraisal of land for natural gas production seems to simplify itself into estimating the income that may be expected from sales and the cost of running the business including development, with appropriate interest adjustments, the work is really complex and the estimates can be raised to the highest possible accuracy only by basing them on a large number of interdependent factors, the value of which are, to a greater or less degree incapable of exact determination.

Ordinarily a good many of these factors receive little consideration, valuations not being made with any great care. Of course the degree of refinement which is legitimate and practical is limited not only by these more or less indeterminate factors but also by the high ratio that should exist between value of property and cost of appraisal. But there is likely to be a growing need in the gas industry for more precise determinations of value, not only preparatory to sales but because of taxation and public utility requirements.

In the past the values of properties have been established by the practical but sometimes disastrously inaccurate method of viewing in a general way the past record of the property and that of nearby or otherwise similar properties with a fairly accurate appraisal of equipment.

Of course the general impressions of an experienced gas man constitute highly valuable material upon which to base valuations but they are not alone sufficient, for additional basis is available and no two properties or periods of time are alike; conditions affecting a single property change more or less as time goes on. Moreover, the performance records that are kept are rarely adequate and often very scant indeed and two properties that appear similar may be very dissimilar.

It should be borne in mind too that the buyer often has in mind a new scheme for utilizing the gas and not infrequently takes over for the purpose a tract that has thus far been unprofitable.

The main questions that arise or should arise when the value of a gas property is to be determined may be listed as follows:

(1) What is the gross acreage?

(2) What portion is known to be gas bearing, what portion promising, what portion is barren, and what probably barren?

(3) What are the sand or sands—tested or untested?

(4) How many producing wells, how many dry and how many abandoned and how are they distributed over the area (map)?

(5) What is the open flow or line capacity, closed pressure and minute pressure or 10 minute pressure of each well?

(6) Are the wells in good condition?

(7) What quantity has been produced and how have the capacities and closed pressures declined with production—how have the wells endured heavy draft? What does this indicate as to life of property—future rates of decline and ultimate yield?

(8) What is the average length of life of a small number of nearby or otherwise similar wells and of a large number of wells in the region?

(9) What have been the performance records of nearby or otherwise comparable wells? In particular what water and other troubles have been experienced?

(10) What is the estimated total quantity of gas and what

will be the most economic rate of production each succeeding year?

(11) What are the size, nature, and distances to market whether cities, oil fields, carbon plants, smelters, or some other kind of market?

(12) What pipe lines, compressors, and other equipment are installed, how efficient are they and what other equipment is needed? In particular, if there is a main line near, is its line pressure such that the wells will feed into it sufficiently freely?

(13) What will be the cost of operating including drilling, expert work, probable losses from accident and other causes, and all other expenses involved in successfully conducting the business?

(14) What will be the gross returns?

(15) What is the quality of the gas? What are its heating value, composition, gasoline, and any other valuable or deleterious contents?

(16) What income will the property yield from sources other than gas, as from agriculture, oil, and coal?

(17) How will the other business activities of buyer and seller be affected by the transfer?

(18) What other gas territory is near and subject to purchase or likely to affect operation through competition or drainage of gas from one property to another?

(19) What are the significant geologic features?

(20) What have been the selling prices of this and comparable gas properties in the region?

(21) What additional indication of value is furnished by (a) estate settlements, (b) appraisals by engineers, (c) assessed valuations and (d) market value of stock?

(22) What allowances should be made for going condition and good-will considering the fact that certain courts have ruled out good-will as an asset of public utilities?

(23) What are the probabilities of damage to the gas pool resulting from drilling for oil?

Of course in preparing answers to these questions it is well to bear in mind that the gas business differs from the oil business

in that (1) gas will not bear costs of much prospecting; (2) a market must often be sought out or developed; (3) the producer, as a rule, must provide and maintain expensive transportation facilities and that much gas is lost in transit; (4) the producer must deal with public utility commissions; (5) on the other hand he needs consider no equipment for refining except gasoline plants, usually no hoisting power or apparatus and sometimes no transporting power; (6) market value of additional acreage is much lower for gas than for oil; (7) the average life of gas wells and gas properties is shorter than that of oil wells and properties and this affects not only duration of supply but usefulness of equipment; (8) the percentage of exhaustion is higher for gas than for oil; (9) on the other hand, the percentage of loss underground is ordinarily higher and above ground much higher, the net result of fraction of the natural store gotten to market being probably though not necessarily higher for oil than for gas; (10) the demand varies from season to season and from hour to hour so that maximum production cannot be maintained continuously; (11) gas migrates more readily than oil and adjoining tracts are drained more extensively by the most active operator; (12) reserve acreage should be larger for gas; (13) ordinarily gas wells cannot be operated singly or even in small groups with profit.

Classification of Data for Appraisal

The data upon which gas land appraisal is based may be classified under six main heads:

1. *Wells and Equipments*: Number and depth of wells and their adequacy as tests of underground supply; quantity, classification and quality or condition of equipment on hand and that needed.

2. *Supply*: Area and sands gas bearing and their richness —known, probable and possible as indicated by tests, well performance and geologic features.

3. *Markets*: Location, size, and character; franchises and manufacturing plants in use, arranged for and prospective, including carbon and gasoline plants, well drilling, local factories, etc.

4. *Transportation facilities*: Pipe lines and compressors installed and needed.

5. *Cost of running business*: Supplies (well equipment, pipe lines, compressors, hauling water, repairs) labor, management, offices, meter reading, expert work, legal expense, losses through accident and other causes, interest on investment and amortization.

6. *Income*: Particularly prices to be expected for gas used for various purposes.

Data for Estimation of Unrecovered Reserves

In many natural gas districts gas is becoming so scarce that appraisals are needed not only to determine what it will cost to get the gas out of the ground and to market and what demand there will be for it but to determine what supplies are available at any price. Although accurate estimates of recoverable gas under any tract of land are unattainable, conditions require that estimates be made. Of course one may attempt too great precision. He may err by considering details and making precise observations to an unwarranted extent, but some sort of appraisal work must be done, and the quality should be as good as conditions warrant. The best estimates of the amount and quality of gas that should be produced from a tract each successive year of the future until the supply is exhausted take into consideration most or all of the following kinds of data concerning the region, the pool, and the tract:

Regional Data

I. Stratigraphy.
  1. Formations—their identity, particularly in comparison with those of other gas bearing regions.
  2. Lithology, or physical and chemical character of materials constituting the formations.
     a. Carbonaceous materials.
     b. Nature and arrangement of large pored ("pervious") and minute pored ("impervious") materials.
     c. Materials to be penetrated by drill and of which account must be taken in finishing and equipping wells, particularly gummy materials, water-bearing materials, and those showing a tendency to cave.

II. Structure.
  1. General dip.

2. Anticlines, domes and synclines.
3. Irregularities of dip.
4. Faults and fractures.

III. Sands.
1. Number and identity.
   a. Known.
   b. Probable.
   c. Possible.
2. Performance records of sands in other fields.

Pool Data

I. Location and extent of gas area.
1. Proved.
2. Probable but unproved.
3. Possible but improbable.

II. History of development and past production.

III. Sands—identity, depth, thickness, and extent.
1. Names.
2. Depth
3. Thickness.
4. Extent.
5. Pores.
   a. Pore space—average and variations of percentage of pore space.
   b. Sizes of pores—range and average—particularly as regards pore connections or smaller portions of pores.
6. Water in the gas sands.
   a. Side of marginal water.
   b. Bottom Water.
   c. Water mingled with gas.
7. Oil in the gas sands.
   a. Side or marginal oil.
   b. Bottom oil.
   c. Oil mingled with gas.

IV. Relation to other fields.

V. Wells.
1. Number, distribution and names.
2. Average number of new wells completed per year.
3. Wells in use and wells closed; also average length of closed period for all wells.

4. Proportions and arrangement of gas, oil and water wells and dry holes.
5. Present and original rock pressures.
6. Capacity and performance records.
7. Spacing.
8. Water encroachment.

VI. Quality of gas.

1. Composition particularly as regards any inert and any enriching gases present.

VII. Pipe lines and compressors.

VIII. Markets—demands for gas for various purposes and competition both among producers and consumers.

IX. Percentage of gas wasted in past operations and probabilities with regard to future operations.

Tract or Lease Data.

I. Name, size, and location of tract, particularly its location with reference to other producing properties, pipe lines and supply stations.

II. Proximity and adequacy of pipe lines and supply stations.

III. Character of country with especial reference to whether it is hilly or flat, how well it is supplied with wagon roads, railroads, water and fuel.

IV. Terms of lease.

V. Number of gas, oil, and dry wells and their distribution with reference to each other and with reference to boundary lines.

VI. Equipment on hand.

VII. Closed pressure, capacity and condition of wells, present and original.

VIII. Production records, and probabilities as to future amount and rate of production anticipating accidents and other difficulties so far as possible.

IX. Probabilities as to drainage of one tract by another.

Methods of Using Data Concerning Reserves.

The methods in which these data are used may be classified as follows:

I. Producing portion of tract, if any.

(a) Pore space method based on size of reservoir and pressure of gas.

(b) Past production compared with (1) Rock pressure decline (2) Capacity decline, and (3) Line delivery decline.

(c) Production curve where production has been maximum and controlling conditions uniform.

(d) Comparison with performance records of wells and tracts that are comparable.

II. Unproven portion of tract and untested sands.

(a) Direct comparison of area with geographically and areally similar producing territory the ultimate yield of which is known or can be fairly closely estimated.

(b) Doctrine of chances, percentage of successful tests in similar structures in region, and output of the average.

After all the most essential requirements for gas appraisal work would seem to be common sense and enough knowledge of the business to bring a realization that the work is complex. Long lists of "cautions" and "things worth remembering" could be made up and used to advantage. In particular it should always be borne in mind that the amount of recoverable gas is limited and appropriate amortization should be planned so that the invested capital may be returned The peculiar hazards of the business should of course be recognized but neither their relative nor their absolute values should be overestimated. In a sense natural gas is not natural—the supplies are exhaustible yet the selling prices depend largely on cost of recovery, transportation and selling. "Supply and demand" seems to fail in controlling price for prices are much the same whether the supply is great or little and whether the market, the size of which commonly varies roughly with the population, is large or small. What is a proper price depends largely on operating costs, the prospecting portion of which is borne partly by the oil industry.

PROBLEMS OF OIL LEASE VALUATION

By Ralph Arnold, *Washington, D. C.*

I used to have the idea that the value of an oil property depended upon the amount of oil that the property contained, but I have since modified my ideas on the subject, and the following discussion will demonstrate the reasons for my change of views.

Every oil property has two values—its market value and its theoretical value. The market value is that established in a transaction between a willing seller and a willing buyer. In other words, it is based on an agreement or compromise between a buyer free from any form of coercion and capable of backing his judgment by cash, and an owner who is under no obligation to part with his property. Property transfers do not always involve a willing seller, as the owner may be forced through circumstances to sacrifice and sell below what would be commonly accepted as the market value of the property; or the buyer might be compelled, through other circumstances, to purchase at a figure in excess of the market value. The motives of all parties to the transaction must, therefore, be taken into account, to a certain extent, in establishing values on the basis of actual transactions.

The value of a property varies from day to day, as is illustrated, for example, by the case of a 40-acre lease in an entirely new oil district. The original lease for the tract might have been acquired for the mere expense of recording the instrument. The value of the lease in this case might be termed zero. Soon other leasers appear and pay a bonus, which increases the value of this property to a moderate bonus, say fifty cents per acre. Still other leasers come in and the bonus rises to $2.50. A well is started three miles away from the property, and the value of the lease rises to $5.00 an acre. A second well is started two miles away, and the lease value goes up to $10.00. Still a third well is located only a mile away, when $25 would be a reasonable market value for the property. The lessee of the 40-acre tract then starts a well himself, and may refuse offers of $100.00 per acre bonus, plus his cost of development to date. A strike is made

in the well a mile away, which jumps the value of the lease from $200 to $500 an acre. A big gas blowout is struck in the well on the property itself, which immediately adds $250 to the value, or a total of $750 per acre. Finally, a good oil sand is struck, and the owner refuses an offer of $1,500.00 per acre for the tract. Other wells are drilled and a settled production of 500 barrels per day is established, worth $2,000.00 per barrel, or a million dollars for the value of the lease, or $25,000.00 per acre. Edge water appears in the next lease and the value of our property drops to $10,000.00 per acre. Edge water appears in the wells of the lease itself, and the owner would be glad to sell for $2,500.00 per acre, but has no offers; hence the value is less than that. Finally, all of the wells go to water. The lease is then worth only the value of the equipment, which may be a very nominal sum. This is sold, leaving the lease stripped and absolutely valueless.

This range of value for the tract may have covered a period of two or three years or of six years. If it happens within six years, it happens within the limit of the period in which we, who are working for the Treasury in this tax matter, have to value properties, and I simply cite this as a quick means of showing you how the valuation doesn't depend necessarily on the amount of oil under the property. It is simply a psychological problem depending on so many factors that it is hard to analyze and determine which one is dominant. In the last analysis, the price of oil properties, of course, depends principally on the price of oil which, in turn, depends at any specified time principally on the quality of oil.

Then the matter of production—the amount of oil that a tract yields per day or per year is, of course, important. We have acquired the habit of using the term "settled production," and I have asked a great many oil men to give me a clear-cut definition of this term; I have found no one yet who can give it. It is nothing that we can define definitely; it is different for different fields; it is different for different wells. I took a series of productive curves and laid them down in front of a well-known oil man and asked him if he would put his finger on the point in the curve where settled production began, and he immediately wanted to know the field which the

curves represented, and asked several other questions, all of which proved the point I was trying to make with him, which was that it is impossible to define that term "settled production". So when you are buying on settled production, you are buying on the amount the well is producing, taking into account many other important factors that enter into the production of that particular property or field.

The price of an oil property does not vary *as* the price of oil—it only varies *with* it—and if we could establish this relation between the price of oil and the price of an oil property—call it a "factor of value"—our work would be simplified very greatly. But it has been impossible up to date to establish this factor on account of the large number of other elements that enter into the proposition.

There is a way to arrive at rough or approximate values in any particular field, especially as regards producing properties, and that is, to get the relation between the ultimate net profit and the value. In other words, you have an oil property for sale and a man may ask you how long it will take to pay out on this property, or how long it will take to get the investment back. That is one of the best gauges, I think, of the value of the property which you can have.

The period of paying out is not the same in all fields, naturally. It depends, of course, on the hazard of maintaining production and a number of other factors, but it is a pretty good barometer as to what the oil men think about valuation. In the Oklahoma field a proposition that would pay out in four years would be considered a good investment, whereas in the Gulf field it might be that the property would have to pay out in a year and a half or two years to be considered safe. In California a property that pays out in five years is not a bad proposition, because we know that the wells there are stable over a long period of time.

In some of the fields values are based largely on the acreage. This is particularly true in California. I have not yet analyzed why one method is established in one place and another method in another, but there are certain reasons why it is so; it it not a mere matter of chance—of a custom grown up without reason. In California you never hear of a property changing hands on the basis of production—it is largely on the basis of

acreage. On the other hand, in certain other oil regions, especially in the Mid-Continent field, you may not hear of the acreage entering into the question of value or being discussed, except incidentally. Of course, where the property is exchanged on the basis of acreage the production does enter into the value, and, vice versa, where the value is measured by production the acreage—especially proven but undeveloped land—is taken into consideration. The equipment which is on the lease and other pertinent facts are given more or less consideration in all cases.

For the purpose of guaging by acreage, we have settled upon a certain rough classification which recognizes producing property, proven property, highly probable, prospective, and, finally, worthless property. The definition of these terms varies in different localities, but they always have a fairly well recognized meaning in each field.

Mr. Beal will take up the discussion of some of the natural factors that govern valuation. I hope that we can do a little team work here and not duplicate our remarks any more than is necessary. I will just briefly run through these factors.

Among the natural factors, few have greater significance than that of stability. This has to do with whether or not you are in a field in which you can depend on the scientific evidence. If you are in a field where you are almost certain to get results, you have an opportunity immediately to establish values along the lines of the various natural factors. In particular, the thickness of pay, the size of pores and aggregate amount of pore space, and the gas pressure, control to a large extent the rate of production per well. Now another valuation factor comes in here, namely, the rate of production. For instance, you might have a structure in Texas that you know would eventually yield 25,000 barrels of oil per acre, and you might have a similar tract in California. In one case you could get out that 25,000 barrels per acre in three years; in the other case, it might take you ten years to recover the same amount of oil. You have exactly the same reserve in both cases, but you know well enough that, other things being equal, you would rather have the land from which you can get the oil more quickly. Some people might say that they would rather tide the thing over, that they believe the price of oil is going up, and so on, but if they had to determine offhand which one they would

rather have, they would take the property that is going to yield the oil the quicker, because everyone thinks he has a good chance to live three years, but he might not be alive in ten years. Even if he knew he were going to live ten years he would in all probability pick the property that gave promise of quickest returns.

Then there is the length of life of the field containing the property. The production being equal, the property in a long-lived field is naturally the more valuable. This factor depends on the length of life of the individual wells and the rate of development.

There are factors that affect values adversely, such as water trouble. You know how that will affect property quicker than anything else. Probably one of the most potent factors in valuation is that of edge water, because it always presages the end of production. Bottom water, and various other water troubles with which you are familiar, must also be reckoned with in appraisals.

Another factor that affects values adversely is depth of wells. The deeper you have to go to get the same amount of oil, the more it costs you, both to drill and to operate, and consequently the less the value of your property.

The character of the formation through which you drill must also be taken into consideration, for it may cost several times as much at one place as another to drill wells of the same depth. Costly drilling naturally reduces your value.

Poor methods of drilling, high price of material, poor labor or the high cost of good labor, excessive cost of equipment and supplies, raise development costs and hence keep down the value of oil property.

The method of recovery is an important factor. If your oil is flowing out freely and costs little to produce, naturally added value is given to the property. When the well settles down and you have to pump, your value falls off somewhat, and, finally, when you have to use a vacuum to recover your gas and oil, the property has reached a point where it is probably not very remunerative and its value is, of necessity, low.

The quality of the oil enters into the problem, the value varying roughly inversely with the specific gravity. Also, the

value of the property varies inversely with the distance from supply stations, particularly during the period of development, when the cost of handling supplies, the character of the country over which you have to haul them, the quality of the roads, etc., enter into the problem.

Transporting your oil after you have it at the surface of the ground is in many fields a serious matter. If you have to pipe the oil a long distance before you can find a market, of course your property is not as valuable as if it were close to the markets.

Those are some of the general factors which probably will be discussed more in detail in following papers.

Now, the theoretical value of oil properties is a matter in which we have been much interested, though it is only one of the side problems of valuation. Heretofore, these theoretical values have been worked out largely on the estimation of oil reserves. There are several methods of estimating oil reserves; a number of them have been outlined, but none of them is more than reasonably approximate. That is all that we can claim for the estimation of oil reserves—an approximation that is reasonable. We have issued a questionnaire in which we ask the taxpayer to estimate his oil reserves. The first man to whom I sent this questionnaire replied that it was physically impossible to determine the amount of oil in the ground and that any sane oil man knew that, and made a few other remarks along the same line, obviously implying that it was a fool question. Now that is the old idea, and that old idea will hold true in a good many cases, for you know you can pick out leases where it is not possible to make a reasonable estimate. But in general, I think all who have had considerable experience know that with the production data we have nowadays we can, as a rule, estimate reserves with reasonable accuracy.

Of these various methods the saturation method and the production curve method are the two principal ones. I may say that we have thrashed over this ground pretty thoroughly in Washington in the Geological Survey, in the Bureau of Mines, in the Fuel Administration, and in the Treasury Department, and we have called in consulting engineers of various kinds and the representatives of the oil men's associations. We have consulted with the heads of the larger companies and have endeavored to get all the information we could. We have come to the con-

clusion that the production curve method is by far the safest method to use in the estimation of oil reserves.

Now, the result that you have when you make use of one of these methods of estimation is in terms either of the ultimate amount of oil that one well will produce, or the amount of oil that underlies each acre. There is a general relationship between the spacing of the wells on the ground and the amount of recoverable oil per acre. The recoverable oil varies with the number of wells per acre or inversely with the number of acres drained by one well. The effect which this spacing has on the value of the property is complicated, depending on the relationship existing between the cost of the additional wells and the value of the additional oil produced. In order to arrive at a proper idea of value based on the theory of recoverable oil, you must outline a drilling plan. Assume that you have a property that is only partially drilled up. In order to find out what the present value of that property is you must find out how much oil it is going to produce this year, next year, and the next year, and so on until exhausted; then find out the present value of the oil taken out each year. That will give you roughly the present value of the property so far as its oil content is concerned. Then you will have to add to that the value of your equipment and the value of the land for other purposes; then deduct the costs of recovering the oil, reducing this, like future income, to a present value basis, and that will give you the total value. This is the method ordinarily used by the appraiser in establishing the value of an oil property.

Most of my remarks up to the present time have been directed toward a producing property. We have also to consider the value of wild-cat properties, which is an entirely different proposition.

In the first place, probably one of the most potent factors is the nearness of the tract to a producing well, and whether the general region in which the tract is located has been tested before, whether it is entirely new to oil development or whether it is an old tract that is being worked over again, and, if it has been worked over, the percentage of dry holes to successful wells that have been drilled in the territory. The geologic conditions are important—whether these are well known or uncertain;

whether they are uniform over large areas or whether they vary locally. Geologic structure also is a very potent factor, as is well known to you operators and prospectors who are dealing in leases here in the north central part of Texas.

The number of wells actually being drilled in a prospective oil region has an influence on values; also the identity of the parties doing the drilling. For instance, you may own a tract of land and John Smith may go over two or three miles from you and start a well. Little or no attention is paid to his activities, for he is unknown as an operator; his work affects the value of your property little or not at all. But let one of the large successful oil companies start the well, and it probably will have ten times as much effect on the value of your property as it would were it someone not well known. The factor of success in the oil business is a very material one; you are willing to follow a man who has succeeded in the oil business, but you are not very anxious to trail behind anybody who is a failure. "Nothing succeeds like success" holds true in the oil business as much if not more than in any other.

The depths of the wells at any specific date in a wild-cat territory may make a difference in values of the leases. As the wells approach closer and closer to the expected oil zone, the operators and speculators become first anxious, then nervous, and prices often double over night on account of little rumors that may have little or no foundation in fact.

The relative quantity of land that is held in the region by any one owner is another factor. We have, for instance, a pool where ninety-five per cent of the land is owned by a large company that you know is going to develop that country—that is going to give it a thorough test. The five per cent of that land that is held by some other parties is worth a great deal more than it would be were the other ninety-five per cent held by many owners whose activities were more or less questionable. The five per cent actually has been increased in fair market value by the general ownership of the rest of the land. Now, in another instance ownership might work exactly the opposite. Where the prospective area is a long way from transportation and the company that is carrying on the development is going to put in its own pipe line, and it announces when it comes in that it is

going to handle only its own oil, these facts immediately have a depressing effect on the values of other properties, because one knows how helpless is the producer who is not in a position to transport or sell his product and is unprepared to store it. The ownership of adjacent property, therefore, is a factor in the value of your own property.

I will now call your attention to some of the indirect factors which will be given consideration by the Internal Revenue Bureau in arriving at "fair market value" of property for the purpose of taxation.

The first one is the factor of cost. How much did the property cost you? I will not go into details in discussing this phase of the subject, because even this factor is governed by a lot of other factors that make it complex, but the factor of cost is the first thing we put down in the questionnaire—What did the property cost you?

Second, have there been sales of other similar properties in the immediate vicinity during the period in which you desire to set up your valuation? The values established by such sales have a very direct bearing on the value of your own property. If you can prove the connection between the value of your property and that of somebody's else property sold on a particular date, you will go a long way toward establishing the value of your own property. It does not necessarily follow that the sale of such property is a direct measure of value of another, because there are a number of other items entering into the calculations. For instance, a man may sell a piece of property. It may be a minority interest and he may sell because he can use his money to better advantage if he can control whatever he is handling, and he may sell out at a low figure, even at a figure considerably lower than he feels is the market value. So this fact would have to be taken into consideration in establishing the value of the whole based on a certain part of the property.

There are cases where people offer to buy and the person who owns the land refuses to sell, and later on the offer may be presented as evidence in the establishment of the value as of the date when the offer was made. Evidence of this sort is often of value, but ordinarily must be scrutinized quite carefully. Right here, I think, is just as good a place as any to discuss

the question of affidavits as they bear on the establishment of values.

About the first thing one thinks of doing when he wants to establish the value of property before the Treasury Department, or any other official organization, is to secure the affidavits of his friends that the property was worth so much at a particular date. I had a little experience of my own, about which I want to tell you, as illustrating the point, and from which I think all of you will draw the conclusion, as I did, that an affidavit is usually worth very little, and for that reason is going to be given little weight by the Treasury Department in establishing the values of properties, unless it can be proved to be of a bona fide and well founded nature. I have a very good friend who had some land acquired prior to March 1, 1913. He wanted to set up the value of this property on his books for the purpose of depletion, under the tax law of 1917, and, naturally, he wanted to set it up just as high as possible. It is human to do this; we all do it naturally; we do everything we can to keep our values up as high as we can properly, if it is to our interest to do so. For some purposes we might want to keep them down. But in this case the man wanted to keep the value up. I received a letter from him saying, "You were familiar with this property on March 1, 1913. There was a certain amount of development there, and I have figured out that this and other land around there was worth so much per acre at that time. Just to save you that calculation I am enclosing an affidavit, and just to save you some more trouble I have jotted down in it the value mentioned, and if you will sign and file the affidavit I will be greatly obliged."

That is a sample of the way in which affidavits are often prepared. My profession is appraising oil properties, and when a person comes to me with a proposition like that, he isn't asking for my opinion, he is asking for the use of my name. He may do all this innocently. I simply cite this to warn you in advance that, when you start in to secure evidence for establishing values, you use only those affidavits whose value can be determined. For example, an affidavit as to an offer to purchase may have a good deal of value. It is a statement given under oath that really means something and it will be given consideration in

establishing the value. It is a different matter from a mere statement that this man thinks a property is worth so much. Unless such a statement is supported by the evidence which he used in arriving at that value, the affidavit will carry very little weight.

The approximate value of an oil property owned by a company that has practically no other assets can be quite easily established from the market value of the stock of that company, if it is listed on the stock exchange or even on the curb exchange. However, this is not a precise evidence of value, because you know that the market value of any stock that is traded in, we will say, at a hundred shares a day, or even a thousand shares a day, may be entirely upset by somebody throwing twenty thousand shares of the stock on the market in twenty-four hours. The market value of the stock of a company that has only one property is not, therefore, a safe criterion to use by itself, but is a good gauge of the public's idea of value and is one of the factors that will be considered.

The royalties and the rentals that are paid for a property, or on a property, are often good criteria to go by. The royalty that a man receives is a clear profit. You can work back from this and find out just what it is worth, and then, based on the fact that in many oil fields a man should get fifteen or twenty per cent on his money, you can arrive at the value of the property.

There are several varieties of Federal tax laws, among them the Income Tax law, under which it is to the taxpayer's interest to establish a high valuation. It was interesting to see how quickly people respond to instinct and set up large depletion and depreciation deductions under this law. Some companies, as was to have been expected, were overzealous in working out their depletion and depreciation and subtracting them from their capital, and in that way reducing their income and making their taxes low. Then Congress passed the Excess Profits Tax law, and the fellow who had been drawing his money out of his business to avoid taxes was left with a very small capital, and his deductions on account of allowances based on invested capital were small and his excess profits tax correspondingly high. Among the taxpayers who have claimed that their business was

being ruined by the excess profits tax were some of the parties just mentioned.

I had the privilege of sitting on the Excess Profits Tax Board, where we heard all these troubles from the various industries in this country. The experiences were often very interesting studies in psychology, because some men had done all they could to increase their depletion and depreciation when they were figuring their income tax, but when it came to the excess profits tax they tried to secure just the opposite result. Ours was a very kind-hearted board and we sometimes let the taxpayer file amended returns and put back some of his depletion into the capital, pay his income tax on the returned sum, and in that way helped him to weather the storm.

It is my advice to anyone who is working on these problems, to work them out on a business like basis. Take the actual amount of depletion and depreciation for whatever purpose you are computing them, put your capital on a reasonable basis, and you will come out better with the tax laws in the long run than if you try to use certain figures in arriving at your excess profits tax and other figures in calculating your income tax. We are going to check up your figures. The Excess Profits tax may not be handled in the same building as the Income tax, but we have telephones and other means of communication in Washington. Hence it is advisable to determine the various tax assessments on the same basis. It is just as much to our advantage as it is to yours to give everybody a square deal, because if we don't—if we work a hardship on the industry, if we stop transfers of property, if we stop development—we are lowering the source of our taxes and we are doing an injustice to the people and to the country, and are not fulfilling the duties that devolve upon us as administrators of these tax laws.

Some more factors that enter into the situation are valuations for local and state taxation. Possibly in some states where they have a direct tax a value is set on oil properties, or they may be assessed at two-thirds of their value, or possibly one-half of their value; but whatever it is it gives us an idea as to relative value in that field, and that is one of the things we are hunting for. In fact, this whole question of taxation is largely one of relative values. I have never yet seen a man who has come

to Washington to have his taxes adjusted but who introduced his remarks by the statement that he did not want to avoid any just taxes but he did want to feel that he was paying his pro rata, and only his pro rata of the total.

We are going to have to collect six billion dollars in taxes for 1919. This enormous sum will be contributed by hundreds of industries. The oil industry is only one of them. If the oil industry as a whole feels that it will be called upon to pay no more than its pro rata, even if that pro rata be twenty-five per cent or fifty per cent, or even seventy-five per cent of its net income, there will be very little dissatisfaction caused, because you feel that you are paying only your share and the other fellow is paying his. It has been the effort of those who have been working on this problem to see that the oil industry as a whole was required to pay its share, but no more than its share of the total amount that was to be collected. When we can figure out in a general way what the industry has to pay, then it is a question of distributing this obligation over the taxpayers who are going to foot the bill, as far as the oil industry is concerned, and all this work, all this talk, and all these meetings we have had in connection with this matter have been to enable us to equitably apportion the payment of the taxes among the people on the basis of their just net income, and avoid taxing their capital. I suppose the point that has been brought forward more than any other in Washington is the fact that the oil industry, the mining industry, and the lumber industry are industries of wasting assets, and that we must be very careful or we shall tax a man's capital in these industries instead of his income. We hope that we can so administer the law as not to tax his capital.

Values set up in partnership accounts are another method of arriving at market value of property. Partners generally know a good deal about the partnership business, and when they come to settle up with each other neither one can get very much the advantage of the other. The basis of any partnership accountings is, therefore, a pretty good basis on which to establish values. You will find in the questionnaire places for including evidence affecting all of these factors about which I have told you.

Here is a peculiar question we have in the questionnaire: Do

you know of anybody who has died recently who held any stock or any interest in a particular property? This is included because the value of any property belonging to an estate is naturally brought up in the court proceedings in settling the estate, and values determined in this way usually are reliable, because the courts can be counted on to weigh the evidence very carefully.

The last thing that I have on the list of factors is disinterested appraisals by approved methods. In other words, this brings us to valuation depending on the amount of oil in the ground. It is one of the last factors that we will consider. You can analyze this statement any way you want to, but it is absolutely true that the amount of oil in the ground, in the final analysis, often has little to do with the fair market price in a great many cases—in the majority of cases, you might say.

One feature of valuation involves sentiment expressed in the old statement, "Great oaks from little acorns grow." There is a little two-line clause in the tax law that says: "In case of leases the deductions allowed by the paragraph"—that's the one for depreciation and depletion and amortization—"shall be equitably apportioned between the lessor and the lessee." That's just two lines. Somebody asked me the other day, "What is an equitable apportionment of the value between the lessor and the lessee?" Offhand you would say, "The pro rata indicated by the royalty rate. For example, one-eighth of it goes to the lessor and seven eighths to the lessee." But if you stop to analyze the situation, you know well enough that that is not a fair basis at all, for the lessor's interest is net while the lessee's interest involves operating costs, etc. There is going to be a lot of trouble, I think, for the Commissioner of Internal Revenue, because it says somewhere else in the regulations that where the lessor and lessee are unable to agree on an equitable apportionment, it is to be left to the Commissioner to say what is right. If you will stop to think of the number of lessors and the number of lessees in this country and the possibility of their referring disputes to the Commissioner, even supposing that only five per cent of them have any trouble, it is going to make a lot of work for us in Washington. I think that for a rule of thumb approximation, the lessor's interest is worth at least twice as much as the working interest in the property. That is, you would rather have an

eighth royalty than a quarter interest in the company that is operating the property, because there are no expenses attached to the royalty. Of course, that is not true if you have flowing wells, because the cost of production is light. The cost of production is one thing if you have flowing wells and quite another thing where the property is operated at great expense, so great, perhaps, that the company does not make anything, as always occurs just before a tract is abandoned. In that case the value of the royalty interest of, say one-eighth may be as great as the value—according to our estimate of values—of the entire interest of the operator of the property. I want to bring this to your attention so that whether you be lessor or lessee, you will get together with the other fellow and adjust your differences.

I think I will finish my remarks by a reference to the influence of geologists in this work of appraisal; in other words, the usefulness of the geologist or engineer in valuation work. I consider his work the missing link between the market value and the theoretical value, and the strength and value of this link will depend largely on the personality, character and reputation of the geologist himself. If he is inclined to be too conservative, I know a certain class of people that will never employ him, that being the class known as irresponsible promoters. If he is extravagant, I know of others who will not employ him—that is, the oil companies that are hunting for properties. You have to meet many conditions in fulfilling the profession of geology—the profession includes more than a mere knowledge of the science of geology.

I used to think that when I had signed a geologic report and turned it over to a man who paid me my fee, my responsibility ended; but it took me only a few months after I went into private work to come to an entirely different conclusion, because my reports in some cases got into the hands of promoters. Some of them had good properties, but they were overcapitalized, and people invested their money because of my connection with the company, or somebody's else connection with the company. I have had widows, orphans, and all kinds of people come to my office and say they went into this or that company because of my connection with it, and it didn't take very long for me to find out that my responsibility went a little further than signing

my report. This is no doubt an experience which the majority of you have had, because the only way we learn these things is by experience. I simply call your attention to the general fact because I feel that the geologist is on the threshold of expanding his activities if he will take hold of the thing in the right way.

The way to lean, if you are going to lean at all, is toward conservatism. I think it is better to be known as a conservative geologist than one a little inclined to be reckless. You are going to be judged by your success in predicting results, and if you become known as conservative, you probably will make more and be of greater service than if you received greater remuneration for a short time by making a lot of exaggerated statements. Just temper all these things with common sense. There is much you can do by studying geology and paleontology and technology, and all that, but in the last analysis, it is a matter of psychology. That is what the whole thing simmers right down to, because business is nothing more than applied psychology.

Another thing—the value of a geologist depends on the width of his reputation. One geologist may be as good as another, but the one who is best known will command the most work and the highest fees. For that reason I have always said that a geologist should not hide his light under a bushel. I think we ought to publish all the valuable material that we can—not only to make it available for the use of others but also because that is about the only way a geologist can advertise legitimately.

I am saying this partly from a selfish motive, for if any of you who come into the American Institute of Mining Engineers, or any of you who are already members, will write a little—will carefully prepare for publication some of the valuable data and conclusions that you have at your disposal, taking care to indicate the basis of your conclusions, you will have something that the A. I. M. E. wants. Possibly you will make mistakes in writing, but at least it will give us a chance to size up your work. We may not employ you for getting out specified reports, we may not have any way to judge of your merits as a geologist or as an engineer, but if you will write a little for publication, it will give us some idea of your capacities and will undoubtedly be to your advantage. During your spare time (if you have any, and if you haven't any, get some) take up a problem that

you are interested in, develop it to a logical, well founded conclusion, and write it up for publication. I know of one geologist—I don't know whether he is here this morning but he is attending these meetings—whose success, I have always felt, started with his pen. He has become quite a fluent writer. He writes a great deal and people like to read his writings, and I think that established his reputation fully as much as the success he has had in locating oil wells.

I called attention a moment ago to the two types of geologist—that is, the conservative geologist and the one who is inclined to be extravagant; also I divided the purchasers of reports into two classes—irresponsible promotor and the oil companies who really want to know the facts. I think all of you would rather be included in the type that is serving the conservative element in the oil industry rather than those who ordinarily bring discredit to it. You are often employed to prepare a report on a property in order to assist in selling the property. If you can make your report just the same whether you are serving vendor or purchaser, you have reached the point where, as was said last night, you are a geologist de luxe. It is very hard to keep your own personal feelings out of the matter, because when you are interested in anything, you are interested in making it look rosy. It is hard to give the hard knocks to the properties that deserve them. When you are trying to keep down to conservatism and you see something about which people are all bubbling over with enthusiasm, especially in a new field, it is pretty hard to settle down and say, "This field is not going to be what these people think it is, because the facts point in another direction." It often requires a good deal of strength of character to get out a correct report.

There are many details we could take up in connection with this income tax problem, but I feel that the best way to reach them is through questions, if we have time for them. After the meeting I would be very glad to answer any questions that any of you desire to ask about the application of either the 1917 law or the 1919 law. I think possibly we can best present the information you people want in that way. For me to discuss all the various details that we must take into consideration, I am afraid would not get the results you want.

There is one vital point that I want to bring up before the oil men today, I have just come from a two days' hearing in regard to it,—and that is, the interpretation of the clause relating to a revaluation of property thirty days after discovery. I touched on the subject last night, but I think it will do no harm to repeat it here today. It is the concensus of opinion of those at Washington who were present at all of the hearings and who were present at all of the discussions before congressional committees, that all of this special legislation is framed to protect the wild-catter and the prospector and the man who takes the excessive hazards of the oil game, and was not intended to give any special privileges to those in the industry who experience no special hazard. The rulings have been made on this basis, and the burden of proof thrown absolutely on the taxpayer to prove in each case that he is entitled to a revaluation or the benefit of the twenty per cent clause in the sale of his capital assets, that he has made a real discovery—it may be the discovery of a new structure, a new field, a new pool, a new sand, a new zone, or a new productive area in the old field that is spotted, as we call it—but he must make a bona fide discovery. Those clauses were not put in to protect the man who sits around and waits for other men to take the hazard and then goes in and puts down a well and expects to receive the same treatment as the one who takes the chance. These special clauses were inserted, I think, to protect the wild-catter, and the other fellow should not get the benefit of them.

A STATISTICAL INVESTIGATION OF THE EFFECTS OF STRUCTURE UPON OIL AND GAS PRODUCTION IN THE OSAGE

By Shirley L. Mason, Pittsburg, Penn.

There is a need for the collection and study of data that may serve in predicting as closely as possible the relative chances of prospective oil lands being productive. Since data of this sort is most applicable to the region from which it was secured, and the greatest need is in partly developed fields where extensive future operations are probable, we must do what we can with the information available rather than attempt to use that from another field which, owing to its complete development, would be more accurate. The territory of the Osage Nation is a field promising great future growth and one that has been carefully covered, in large sections, in U. S. Geol. Survey Bull. 686. The material contained in this bulletin has been analysed and while the relative incompleteness of development makes our findings necessarily preliminary, we think that, pending further publication, they will be an aid to location and appraisal.

Purpose

The data[1] has been compiled to show, as far as possible, the relative value of the different types of structure in the Osage Nation, the relative value of structures of different size of the same type, and the relative value of various portions of the same structure. The proportionate value of locations in every compass direction on or about the structures has also been worked out. For the actual value, of course all local factors such as thickness of sand, amount of pressure, and so forth, as well as cost of production must be considered.

Methods

The references to production in the sense of the number of

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[1]The methods employed in this paper have been furnished by Prof. Roswell H. Johnson, University of Pittsburgh, under whose guidance this work has been done.

barrels of oil, or cubic feet of gas per day from the individual wells were too vague and scarce to form any basis of analysis, so that thruout this paper the terms *productive* and *productiveness* mean simply that the wells were marked as producing gas or oil.

The term *well,* used alone, covers any completed hole put down for oil, whether it results in an oil well, a gas well, or a dry hole. Oil wells include those marked as oil wells and as abandoned oil wells. The same is true of gas wells. The dry holes include those so marked and those few marked "show of gas" or "show of oil."

Structures have been classified into domes, basins, related areas and unrelated homoclines, and the entire region covered is divided among these classes.

A dome is considered such only when there is a definite closure of the contour lines shown. The space between each of these contour lines is considered a zone, the first zone lying between the lowest closed line and the next one up-dip, numbering to the top of the dome and calling the space enclosed by the innermost line the final zone. These contours have a ten feet interval.

The term *basin* is used as the opposite of dome, being a syncline with complete closure as the other is an anticline with closure. The basins were treated in the same way, save that here the numbering was from the upper edge down to the final zone. With both domes and basins the space lying between the first zone and the adjoining contour which fails to close, is considered the Basal Zone.

The structures have been made out by a strict following of the maps and where the exact number of zones has been uncertain owing to a portion of the structure falling outside of the townships mapped, the entire structure with its related wells has been discarded.

All pools whose up-dip edges overlap a closed contour or approach within one or two zones of closure have been classified as on *related areas.* This general term is used to cover an area which is for the most part plane-dipping homocline, but with a small portion plunging anticline or syncline, so that a more defi-

nite term would be inaccurate. This related area extends down to the apparent limits of the pool. These related areas are also divided into zones, using the same contour interval, and beginning with the one adjoining that basal to the structure in the numbering.

All wells not included under these three headings fall on unrelated homoclines, a term which is self explanatory.

Faulted domes and basins are omitted from this preliminary paper where the dome is so disturbed that the zones are not readily traced.

Tables

The following table of domes, divided into those containing 1, 2, 3, and 4 zones, give the percentage of wells producing oil or gas in each of the zones. Domes containing more than four zones were not drilled upon in more than one instance for a given size, so that they are omitted from this table.

Productiveness of Domes by Zones

Type of Dome	No. of Wells	No. of Domes	Total Oil or Gas for Structure
One Zone	51	9	80%
Two Zone	67	13	83.2%
Three Zone	42	4	93.2%
Four Zone	43	4	86.6%

Percentage of Gas Wells

	Basal	1st Zone	2nd Zone	3rd Zone	4th Zone
One Zone	95	70			
Two Zone	51	67	12		
Three Zone	59	52	40	33	
Four Zone	61	37	40	50	16

Percentage of Oil Wells

	Basal	1st Zone	2nd Zone	3rd Zone	4th Zone
One Zone	0	10			
Two Zone	30	28	25		
Three Zone	41	35	60	66	
Four Zone	31	56	40	50	66

Percentage of Oil or Gas Wells

	Basal	1st Zone	2nd Zone	3rd Zone	4th Zone
One Zone	93	80			
Two Zone	81	95	37		
Three Zone	100	87	100	100	
Four Zone	92	93	80	100	82

In the column showing the percentage of success on the structures as wholes, there is an increase with the increase in size, a tendency which is carried out by the results from the larger structures which were not included in the table.

5 zone (Buffalo) dome 1 well giving 100% gas

7 zone (Avant) dome 69 wells giving 96% gas or oil

8 zone (Bald Hill) dome 220 wells giving 94% gas or oil.

The decrease in percentage of oil production in succeeding higher zones is partially compensated for by an increase in gas production, but taking them together, the increased value of higher zone that might be expected is not found. This is further shown by the following table showing the percentage of productivity of all domes, divided in to top and bottom halves:

Effect of Position on Dome on Productiveness

	OIL		GAS		OIL & GAS	
	%	No. of Wells	%	No. of Wells	%	No. of Wells
Upper Half	60	37	29	18	89	55
Lower Half	75	136	18	34	93	170

The basins tabulated according to zones, give the following results:

Productiveness of Basins by Zones

			Percentage of Oil Wells				Total for
Type of Basin	Case	Wells	Basal	1 Zone	2 Zone	3 Zone	Structure
One Zone	3	5	33	0			20%
Two Zone	5	35	81	66	75		74%
Three Zone	2	4	0	0	0	0	0

Note:—All production in the two-zone class occurred in a single basin.

The absence of gas wells in these basins shows a confirma-

tion here of what might be expected theoretically. The occurrence of oil wells, in one case in such comparatively large numbers, is of interest. It shows that an area is not to be absolutely condemned because it lies in a basin, although as the following results show, the chances are against any given basin proving productive.

In the following tables each structure is entered as a unit and called productive if there is one or more oil or gas wells on it, to distinguish from those condemned by dry holes;

Frequency of Productiveness of Drilled Basins of Different Depths

	DRILLED				NOT DRILLED
Class	Non-Productive Basins	%	Productive Basins	%	Basins
One Zone	2	66	1	33	27
Two Zone	4	80	1	20	7
Three Zone	2	100	0	0	2
Total	8		2		36

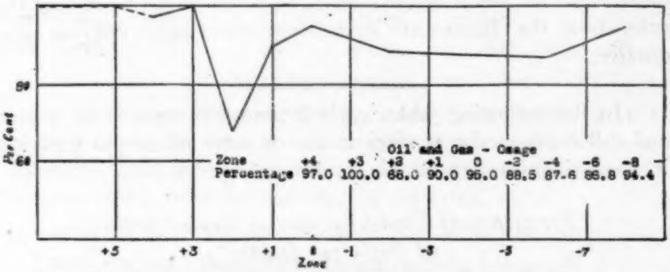
Frequency of Productiveness of Drilled Domes of Different Heights.

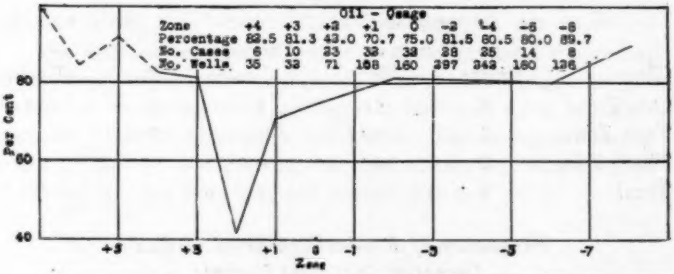
	DRILLED		NOT DRILLED		
Class	Non-Productive Domes	%	Productive Domes	%	Domes
One Zone	3	33	6	66	15
Two Zone	1	07	12	92	13
Three Zone	1	20	4	80	3
Four Zone			4	100	5
Five Zone			1	100	1
Six Zone					
Seven Zone			1	100	
Eight Zone			1	100	
Total	5		29		36

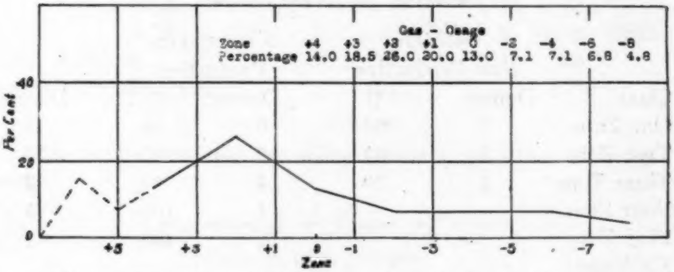
This shows that a high percentage of domes are productive, this percentage increasing in general with the increased height of the dome. With the basins the case is reversed.

Taking all wells on domes and related areas, divided as to the

position of the zone in which they occur, the following percentages of productiveness are obtained.







Note:—The dotted line extending beyond †4 shows the percentage in the one or two cases where we have any wells beyond that point.

Note:—The upward turn of the curve between -6 and -8 is due to the weight of the Candy Creek pool which reaches its highest productiveness in the -8 zone and falls off in either direction, possibly due to a lenticular formation.

Making a broad allowance for the irregularities in the curve, due to the lack of enough data to smooth it out, these in general show a much slower decline in productivity as one goes down structure, than is usually supposed.

A summary of the percentages of productivity of the different types of structure is given in the following table. The basal zone is included as a distinct class to avoid classing it with the domes or with the related areas.

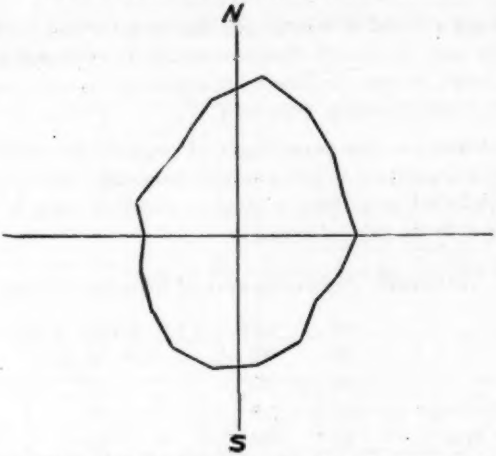
Comparative Productiveness of Structural Types

	OIL %	GAS %	TOTAL % Oil or gas	NO. OF WELLS
All Domes	68	20	88	250
All Basal Zones	81	10	91	197
Related Area	83	06	89	911
Basins	64	0	64	44
Unrelated Homoclines	20	07	27	53

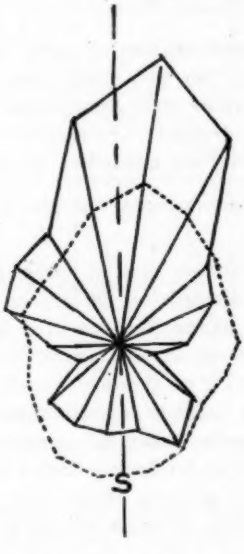
In view of the small number of cases, these cases must not be applied too literally, but they show domes and their related areas as the most favorable types of structure, while of these the domes show the most frequent occurrence of gas. The basins and unrelated homoclines are much less favorable.

Location of Productiveness about the Center of Structure according to Direction.

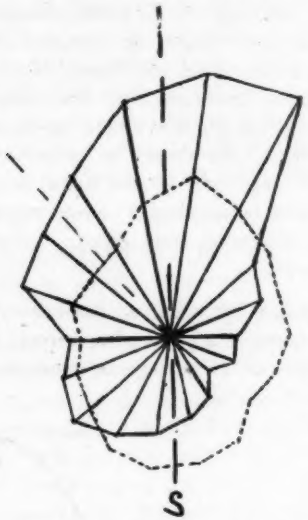
In the following figures the oil wells, gas wells, and dry holes were separately divided into 20 degree polar segments radiating from the center of the dome, counted, and laid off proportionately to their number, on the central line of the segment. These included those lying on the domes and their related areas. The figure showing the shape of the structure was made by averaging the distances from the center of structure at which the outside closing contours of all productive domes crossed these 20 degree lines. This figure, which is given below and also in dotted lines on the other figures, is made on the scale of the Survey maps, namely 1-31250.



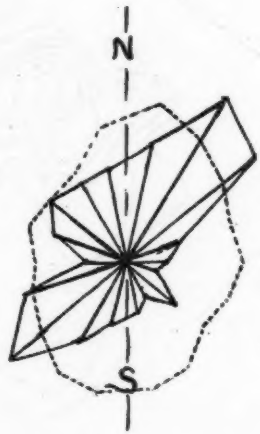
Average Size and Shape of Production Domes in Mapped Portion of Osage.



Polar Frequency of Distribution of Gas Wells about the Center of the Domes Studied.



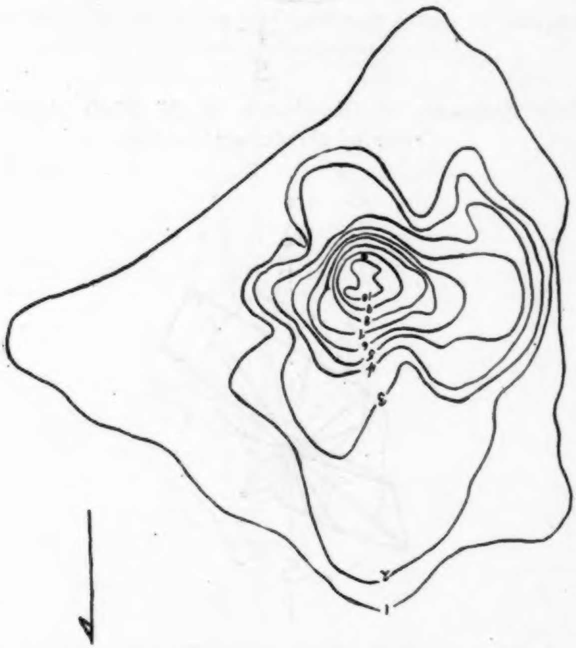
Polar Frequency of Distribution of Oil Wells about the Center of the Domes Studied.



Polar Frequency of Distribution of Dry Holes about the Center of the Domes Studied.

In the figure showing the oil productiveness, the dotted line 40 degrees west of north marks the direction in which the greatest number of wells lies from the center, if we compare 180 degree segments. This direction from the center of the dome is the one in which there is the best chance of striking oil in making a test. The failure of the domes to exceed the northwest segment of the basal zones and related areas in productiveness, is. we believe, mainly to be attributed to convergence and the direction from which migration took place. Lateral variation also contributes, of course.

By superimposing the areas of the several gas pools, using the center of the dome as a point of reference, we get a series of concentric isographs of frequency of productiveness, as shown below:



Superimposed Gas Pools—Osage Domes. Scale 1-31250

This shows in another way much the same result as the figure above giving the polar frequency of distribution of gas wells, but we may measure here both the influence of direction and the effect of distance from the center of the dome. The center of gas production lies 660 feet north of the center of the dome. We shall do this with oil as soon as data is fuller. Oil is more extensive and irregular in its isographs. The Osage should be divided both geographically and by its sands when data is adequate.

Summary

Locations on domes and their flanks have greater chances of success than those on basins and unrelated homoclines. These chances might be expressed roughly in the proportion of 4 to 1.

No territory is to be condemned as worthless because it covers unfavorable types of structure.

The larger the dome, the greater the chance of a successful test. Such a test should be located on the side rather than the top of the dome. For gas this should be directly north, the distance varying with the size of the dome, but it should be within the highest contour, about 660 feet from the center. For oil it should be at about the level of the closing contour and about 40 degrees west of north from the center.

AGE OF THE BEND SERIES

Joint statement by George H. Girty *and* Raymond C. Moore.

At the recent meeting of the American Association of Petroleum Geologists at Dallas, Texas, papers on the age and correlation of the Bend series were presented by the writers which contained differences not only in some of the conclusions reached but in some of the statements of fact. The differences were indeed so great that it was almost certain from the first that different things were under consideration or that the same terminology was used in different senses. A frank interchange of views soon proved this to be true, and as the writers find themselves largely in agreement concerning the evidence it has seemed desirable, the matter involved being not only of private but of public interest, to prepare this joint statement. The crux of the diversity of views expressed in the papers appears to lie in a different use of the terms Lower Bend shale and Marble Falls limestone.

At the type locality of the Bend series, near the village of Bend on Colorado River, eastern San Saba county, the geologic section, for the purpose of this discussion, may be divided into four beds. The basal part of the series consists of fissile, black shale or, locally, yellowish clay shale which ranges in thickness up to 50 feet. This may be designated Bed A. The basal shale is succeeded by a thick limestone division, approximately 400 feet thick, which in places contains interbedded shale and shaly limestone. It will be necessary in this statement to distinguish the lower part of this division, which may be designated Bed B, from the upper part, which may be designated Bed C. Bed C is overlain by a fissile, olive colored and black shale about 300 feet in thickness, which may here be designated Bed D. These divisions comprise the so-called Bend series.

In the geologic study and mapping of the Llano-Burnet quadrangles beds which without question belong to the Bend series were observed. Two stratigraphic divisions, based on lithologic differences, were recognized; a lower limestone formation, maximum thickness about 450 feet, which from beautiful

exposures on Colorado River near the town of Marble Falls was named the Marble Falls limestone, and an upper black shale formation, maximum thickness 400 feet, named the Smithwick shale from the old town of Smithwick, east of Marble Falls. It is clear that these formations are equivalent in a general way to Bed C and Bed D respectively of the Bend series at Bend and elsewhere in San Saba, Lampasas and McCulloch counties. The basal shale (Bed A) observed near Bend is not present at Marble Falls and investigations by both writers lead them to agree that at least the lower portion of Bend B is likewise absent. The upper part of Bed B may or may not be represented there. Hence, the Marble Falls limestone as seen at its type locality seems to represent only Bed C of the section at Bend.

The basal Bend shale (Bed A) contains few fossils but the remaining part of the Bend series are quite fossiliferous. So far as the facts are at hand the fauna of Bed A is closely similar to that of the lower portion of Bed B and no evidence of disconformity or other crosional break between the two divisions has been observed. Large collections obtained by both writers from Bed B are characterized by very abundant *Liorhynchus carboniferum, Glyphioceras cumminsi (-G striatum?) and G. incisum (-G. crenistrium?)* which in the absence of typically Pennsylvanian types give the fauna a distinctly Mississippian facies. Bed C at Bend and in the adjacent region is abundantly fossiliferous at several horizons, and the faunas, as agreed by both writers, belong without question to the lower Pennsylvanian. The Smithwick shale (Bed D) which succeeds the Marble Falls limestone without break has a distinctive fauna and is evidently Pennsylvanian.

In Girty's paper Bed B was included with Bed A under the term basal Bend shale, because he saw Bed B only in much weathered outcrops where it looked like a calcareous shale or marly limestone. In his usage the term Marble Falls limestone was essentially the same, therefore, as Bed C, which is already indicated is approximately equivalent to the formation as observed at its type locality.

As identified by Moore the basal Bend shale is the black, fissile, bituminous shale and the yellow clay shale (Bed A) which underlies the fossiliferous horizon of Bed B as here defined.

Where observed by him the latter is a dark, fine-grained, hard limestone, sharply differentiated lithologically from the underlying shale and continuing without observed stratigraphic break or marked lithologic change into beds which are undoubtedly equivalent to the typical Marble Falls limestone (Bed C). These relations are specially well shown at one locality in upper Cherokee Creek where the beds in question are exposed from the Ordovician to a point 155 feet above the fossiliferous horizon (Bed B) at the base of the Limestone.[1] In Moore's paper the term Marble Falls limestone was hence used for the entire limestone division (Beds B and C as here defined) between the basal shale (Bed A) and the Smithwick shale (Bed D).

It may be pointed out that the faunal evidence and stratigraphic observations of the writers appear to be in essentially complete agreement. The opposing views as to the age on the lower part of the Bend are, however, maintained for the present as expressed at the Dallas meeting, Girty holding that Beds A and B as here designated are Mississippian, and Moore that they are properly referred to the Pennsylvanian. The writers have in prospect a joint paper on the Bend fauna to which each author will be able to take into account the evidence known at present only to the other. In the light of new evidence either author may feel justified in revising his views.

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[1]See Stratigrahpic section, Moore's paper.

DECLINE CURVE METHODS

By ROSWELL H. JOHNSON, *Pittsburg, Penn.*

The essential tool to any one who would appreciate an oil and gas property or determine its rate of depletion, is the decline curve. Since the applications of the appropriate statistical and graphic methods desirable for an understanding of the decline curve have not received adequate attention, it seems to me that it might be helpful if on this occasion I presented an outline of the application of these methods in the construction of decline curves.

In the study of the production of oil or gas wells we may use statistical or graphic methods for three different purposes:

I. To show the production in successive units of time, such as a year. Curves of this type are always shown with the amount of production on the ordinate and time represented on the abscissa. If the data is directly shown this curve will show a regular slope downwards except occasionally where the sand is very soft for a short period in the early history of the well. Such curves are called decline curves, or if the data is shown as a table, as decline tables.

II. To show the amount of total or past or future oil. Such curves usually plot this amount against either the age or the size of wells or both. Such curves have been designated appraisal curves by Lewis and Beal, although they do not represent appraisal directly, but only quantities useful in making appraisals.

III. It may show the correlation of two contributing factors which control production. Such curves are called regression curves.

IV. It may show the relative role of three contributing factors or a result as effected by some given two contributing factors. These curves are called isographs.

A. Decline Curves.

1. Unit.

a. and b.. The unit on which a decline curve may be based may be a single well or we might take a group of wells, all of the wells being of the same age; that is the first year of one well is averaged with the first year of another well, regardless of the calendar year in which the well was drilled. The curve may show a number of these wells aggregated or an average of such an aggregate.

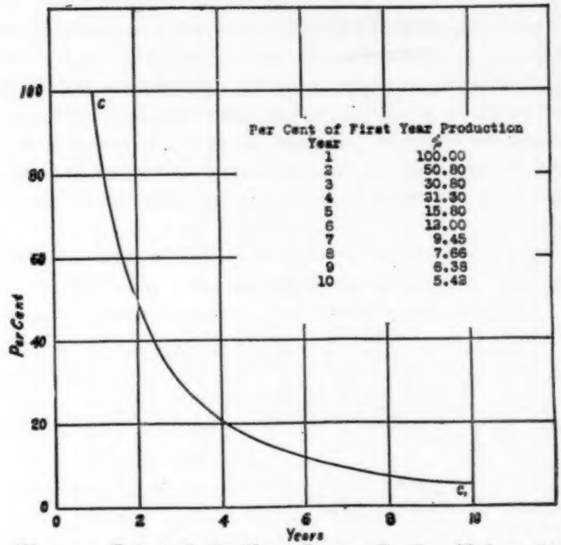


Fig. 1.—Selected Decline Curve C. C. Taken from Data of Fig. 6.

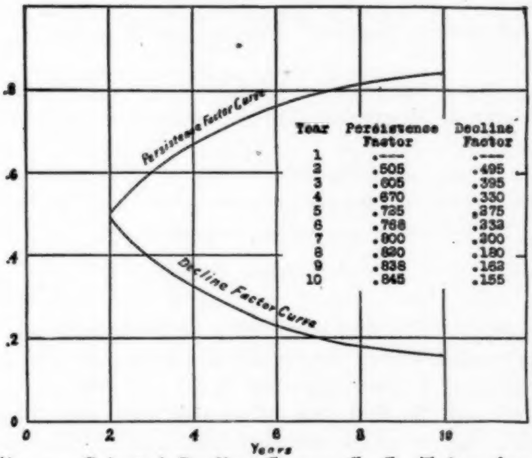


Fig. 2.—Selected Decline Curves C. C. Taken from Data of Fig. 6.

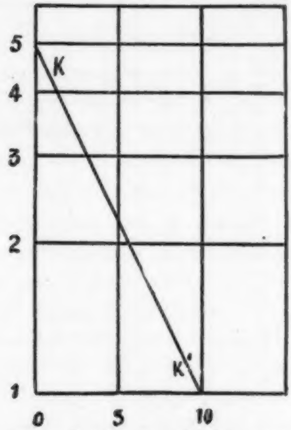


Fig. 3.—Curve Showing Data of Fig. 4 on Arithlog Paper.

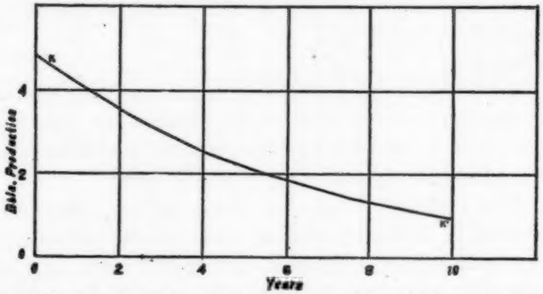


Fig. 4.—Curve of well producing one barrel during tenth year, after having fifteen per cent. fall-off each year on Quadrille paper.

c. The production of several wells may be combined on the basis of the calendar time unit, that is to say the production of certain wells during the year 1917, ignoring the age of the component wells. This is the usual method in practice. The wells of one tract being combined gives the production measured collectively which best serves the financial purpose for which the data was collected, or an average of the component wells can be given instead of the total.

2. Use of derived indices.

a. It is sometimes desirable for the purpose of comparison to express production in terms of percentage of the first year. By so doing any particular year is put on a convenient basis for comparison with that same year's production for another well. The labor of computation involved is not great where a reckoning table of the fittest scope or a slide rule is employed.

b. Instead of expressing the production as terms of the first year, it is frequently more desirable to express it in terms of the previous year. We then have a rate of decline for that year. Since this number is an expression of the production which persists from year to year it may well be called the persistence factor. With this factor in mind the production of any one year is obtained by multiplying the production of the previous year.

c. Upon other occasions it is better to have an expression of the complement of this number, that is of the rate of fall-off. This factor may be called the decline factor and measures the percentage losses sustained.

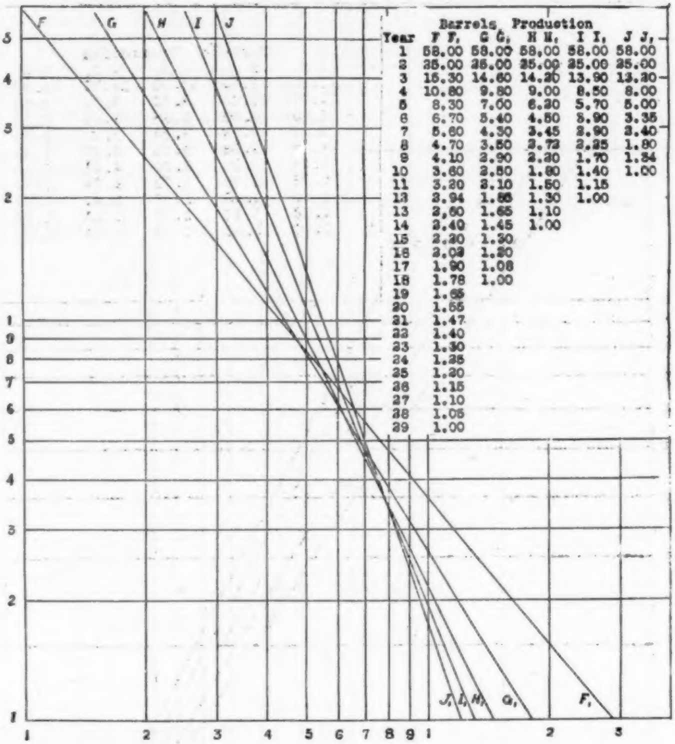
3. Ruling used.

a. Of the four types of ruling upon which the data may be plotted, the quadrille is the most common. In this paper an arithmetic scale is used both for the ordinate and abscissa. It has the merit of simplicity and is most widely used.

b. The arithlog or semi-log paper has an arithmetic scale for the abscissa, and a logarithmic scale for the ordinate. Where the persistence factor is uniform, the decline curve is a straight line upon this paper. It is useful for testing the tendency of curves to become exponential and also for curves which extend from very large amounts to very small amounts on ordinate, since the smaller amounts are easily read. It is best for price curves as equal rates of price change show equal slopes.

c. Logarithmic paper has each scale logarithmic. The great value of this paper lies in the fact that the hyperbola (which most decline curves approximate) becomes a straight line plotted on this paper. Extrapolations of oil production curves then are usually made with logarithmic paper.

d. Polar-coordinate paper constructed with radius and circles is useful where one of the quantities to be expressed represents directions or angles. While not used for decline curves,



	Barrels	Production			
Year	F F,	G G,	H H,	I I,	J J,
1	58.00	58.00	58.00	58.00	58.00
2	25.00	25.00	25.00	25.00	25.00
3	15.30	14.60	14.20	13.90	13.20
4	10.80	9.80	9.00	8.50	8.00
5	8.30	7.00	6.20	5.70	5.00
6	6.70	5.40	4.50	3.90	3.35
7	5.60	4.30	3.45	2.90	2.40
8	4.70	3.50	2.72	2.25	1.80
9	4.10	2.90	2.20	1.70	1.34
10	3.60	2.50	1.80	1.40	1.00
11	3.20	2.10	1.50	1.15	
12	2.94	1.85	1.30	1.00	
13	2.60	1.65	1.10		
14	2.40	1.45	1.00		
15	2.20	1.30			
16	2.03	1.20			
17	1.90	1.08			
18	1.78	1.00			
19	1.65				
20	1.55				
21	1.47				
22	1.40				
23	1.30				
24	1.25				
25	1.20				
26	1.15				
27	1.10				
28	1.05				
29	1.00				

Fig. 5.—Some Logarithmic Curves of wells producing fifty-eight barrels a day for first year and an original persistance factor of .434.

it is here mentioned because valuable for isographs referred to later.

4. Method of smoothing.

a. Curves which are frequently irregular because of the small numbers involved would be more regular if the numbers were greater. One of the devices for smoothing such a curve is the moving average. In this method each number is averaged with an equal number of numbers next preceding and following

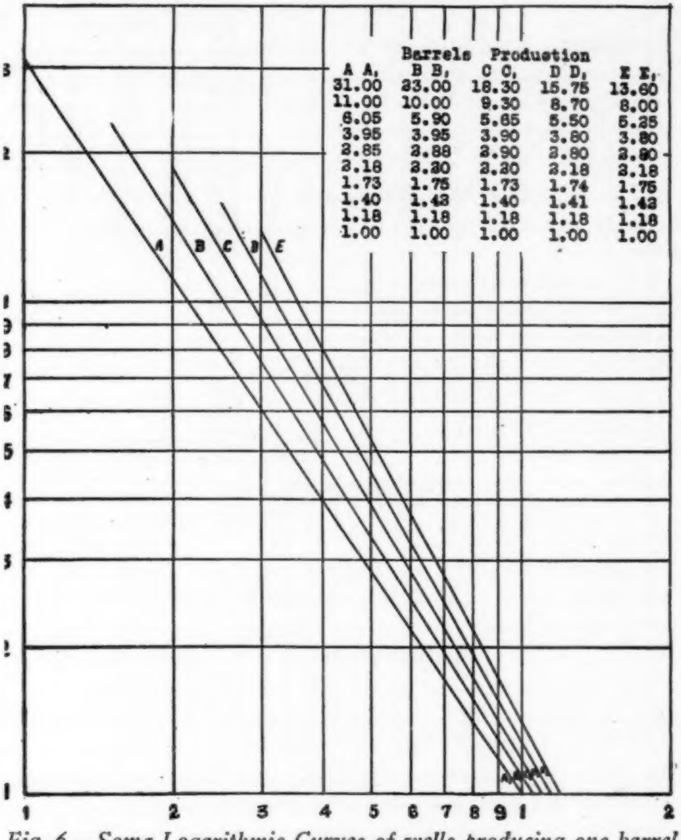


Fig. 6.—Some Logarithmic Curves of wells producing one barrel during tenth year and having a persistance factor of 85. *Curve C. C. is shown in several other figures.*

The curve made from these averages has the effect of reducing deviation from the general trend of the curve.

b. Logarithmic paper is useful where the curve is an hyperbola or approaches an hyperbola and arithlog paper where the curve is exponential or approaches an exponential curve, because after plotting several points a straight line may be drawn

which will throw equal numbers of points on each side along its course. This straight line may then be plotted back on to quadrille paper and will yield a smooth curve.

c. When such a line which is known to be a straight line on logarithmic paper is transferred to quadrille paper it of course has angles at the point of plotting. It may be converted into a smooth curve by using the curved edges constructed for drawing special curves. By selecting the proper part of such a curve the smoothing is easily accomplished.

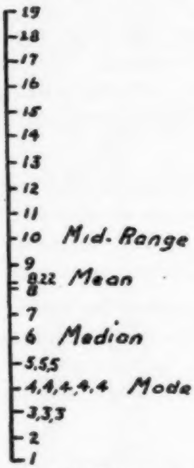


Fig. G—To illustrate Mid-Range, Median and Mode.

d. If the curve departs too much from the hyperbola for the use of the logarithmic paper, plot the persistence factors. The persistence factors of a logarithmic curve constitute a regular curve, although it is neither hyperbolic nor exponential. The rectification of irregularities in the persistence factor curve will smooth out the original curve if reconstructed from the smoothed persistence factor curve.

e. Freehand sketching may, of course, be resorted to in other cases.

5. Average used.

a. *i.* Averaging data offers a much greater range of choice than is usually supposed. Thus in the selection of the divisor

shall we take the number of wells which are still producing on a certain tract or should the number of wells be taken which the tract contained when the study is started, or when at a maximum. The average of the surviving wells is necessary in studying costs per well, but the latter practice is desirable when studying the production of the tract.

ii. The constituent well method may use as its divisor the number of wells at the time of maximum development or at any time of reference for the study in question.

b. There are four different methods of ascertaining the average of a series of numbers. The one which is generally used is the arithmetic mean, and while often satisfactory is in some cases dangerous by being too much influenced by a few extreme cases.

If then we take instead of the mean, the magnitude of the middle case or the median as it is technically called, this is not sufficiently influenced by the extremes, but it gives a much better idea of the typical value than the mean.

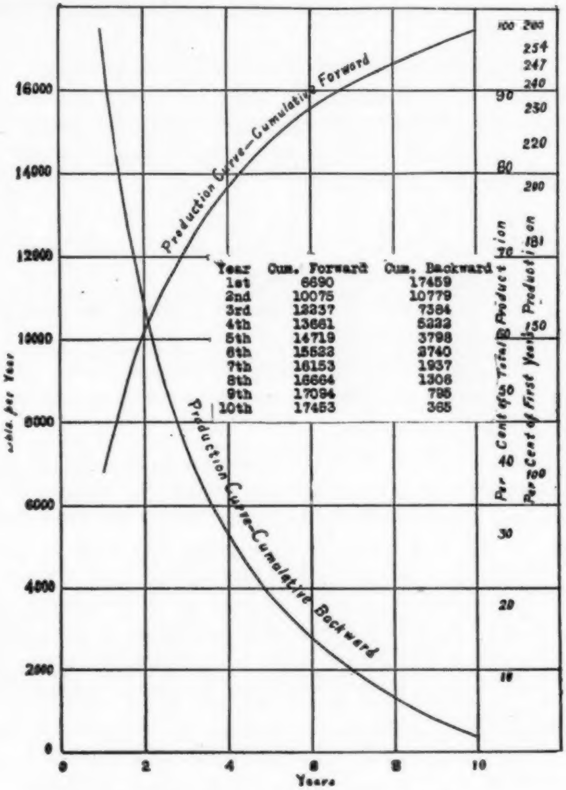
If, however, we particularly desire to know the typical condition with little reference to the extremes, the mode or the most frequent number may be utilized. This average is not sufficiently influenced by extremes, and does not adequately utilize the facts of distribution.

6. Compounding a curve.

a. It is often true that the knowledge desired is not obtainable from any one curve, but that a very useful curve may be made up by compounding several curves. Merely averaging will often not suffice because the material at hand may represent different periods in the age of wells. This compounding may be accomplished by allowing each of the several segments of the curve to be calculated separately, or a curve may be built up by overlapping or shingling. If the segmental method is used the average length of time that it takes the wells of a certain average size to reach a given average size may be plotted and the next corresponding unit drawn. This method has been more especially developed by Mr. James L. Darnell.

On the other hand we may take as the segments equal time intervals and plot the amount at the beginning and end of a year.

In this case several segments may overlap each other, or on the other hand leave a gap, in which case by the use of logarithmic paper the overlapping and gaps may be adjusted. The curve should start where there is least overlapping or gaps. The segmental curve is a valuable method, but in its application it is extremely difficult to find small wells which truly represent the future history of the large wells, since most of the small wells decline more rapidly than the large wells will when they are equally small. This is owing to the fact that small wells in the earlier history of the pool are generally small because of some



Year	Cum. Forward	Cum. Backward
1st	6690	17459
2nd	10075	10779
3rd	12337	7384
4th	13661	5222
5th	14719	3798
6th	15523	2740
7th	16153	1937
8th	16664	1306
9th	17084	785
10th	17453	365

Cumulative Curves constructed from C. C.

limitation of thickness or porosity, and since they are producing at a higher pressure have a more rapid decline than the larger wells do in the later history when the pressure decline is smaller.

b. In compounding one curve from several by the shingling method we may start at the beginning and work forward, placing each given curve on the appropriate point of the previous curve extending forward, or we may start with the last and smallest values and proceed backward. The compound curve itself is then derived from the several curves drawn either by calculating an average, or by sketching or selecting one that is deemed the most satisfactory as a representative curve. This method we owe to Lewis and Beal.

7. Methods of extrapolation.

There are four methods by which we extend the curve past that portion which has been constructed from the data in hand.

a. Extrapolate by determining the formula of the curve and calculate the future years.

b. By placing the curve on that type of ruling and with that origin which gives the straightest line, we may extrapolate by extending the course of the curve.

c. We may extend by adopting such future persistence factors as seem most probable from analogy.

d. We may draw in several analagous curves and then sketch the extension, guided by the course of those curves.

8. Cumulative curves.

a. Instead of each value being determined solely by the data of the year in question we may have the ordinate of each year indicate the sum of this and all previous years, or the sum of this and all later years. Such a curve may have in addition to its regular scale another scale showing the same amounts expressed in percentage of the first year or in percentage of the total amount. In this last case this percentage is in reality the ratio of the past and future production, and gives us an opportunity of calculating future production by simply multiplying the past by that percentage.

Appraisal Curves.

1. Two-fold.

Appraisal curves or tables are made for the purpose of being

able to read either the total production of the well or the future production, having given certain data. Since Lewis and Beal have shown that the size of the well is the variable which in general has the highest correlation with production, such curves show the production of the first year or of any year of reference against either the total production or the future production.

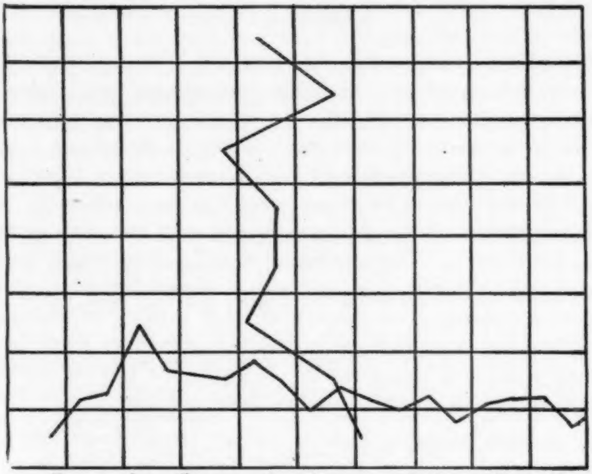


Fig 9.—Regression Curves showing correlation of yearly production and persistence factor of a group of wells.

It is curves of this type which are attracting so much attention just now for depletion studies.

2. Three-fold.

The size of the well, while it is the most important variable, is only one of several factors. It is quite possible to make a curve or table which will show the influence on total production of two different factors. Thus the persistence factor, the past year's production, and the future or total production may be shown. The method used is to plot one of these factors on the ordinate and the other on the abcissa, and instead of using points write a number indicating the magnitude of the third item at the point indicated. Equal values of this third item are now connected and give isographic lines. This method is the same

method used by all geologists in making structure contour lines. Another familiar use of the isographic method is the isobars of the weather map. By giving values to these successive isographs, having regular intervals, the third value is easily read. It is to be hoped that as soon as data permits that such three-fold appraisal curves and tables will replace the two-fold ones.

C. Regression Curves.

In addition to these types of curves it is frequently desirable to study the degree of correlation between any two factors influencing production. Thus if we would find the influence of spacing or thickness of sand, dots should be entered on a quadrille diagram. The number of dots in each square being determined by the number of cases, we show the combination of a given magnitude of the attribute A and with the corresponding of the attribute B. The number of dots in each compartment is counted and in that way by any one of several formulae we may compute the index of correlation, or what is more informing, we may draw the regression curve which is the curve made by the average of all dots in a column. It shows the relative influence of each of the two factors studied upon the other.

It is very desirable, indeed, that we should know more exactly the relative role of the several factors, in as much as appraisal demands not a knowledge of qualitative influence, but an exact weighing.

PART II.

A. The Nature of the Decline Curve.

The individual oil well decline curve approaches a regular hyperbola, as has been shown by Lewis and Beal. A formula can be more readily established for the curve, and correspondingly there is a better fit to any one hyperbola where the time unit used is a year. The deviation from the hyperbola is greater when the time unit is a quarter, a month, a week or a day. In any event deviation from any one hyperbola is greatest in the very early history of the well and again in the later history. There is this difference, however, that in the very early history the form is still hyperbolic, but with a different formula, whereas in the very

late history the curve departs from the hyperbolic form and increasingly approaches an exponential formula.

A little reflection indicates that this is just what we should expect. Early in the history of the well the oil is more thoroughly distributed through the pay vertically so that the expulsive force of the gas acts on the oil as a whole to a greater degree. But in sands which are not too fine in the later history of the well, the oil is drained less rapidly from the lower part of the sand than from the upper part, so there is an increasing tendency for the gas to go directly into the hole through the upper part of the sand, and hence not exert its full expulsive force. The hyperbolic curve is the result of the fact that the production of the oil is the result of expulsion by pressure as pointed out by Lewis. But as short-circuiting takes place and as adhesion plays an increasing role, the curve, owing to decreased pressure, approaches an exponential formula.

The fact that the equilateral hyperbola is rarely if ever attained, but that the curve is that of a hyperbola which has its origin somewhat shifted is thought by Lewis to indicate the presence of factors interfering with the pressure expulsion, and this seems quite probable.

When we turn to the production of a gas well there has been very much less work done, and it is somewhat less consistent. The reason lies in the fact that the curve is influenced by the rate of pull on the well, in contrast to the oil well, which is ordinarily caused to produce all it will at all times. It is probable that a gas well which was not influenced by encroaching water and which was allowed to produce all it could, would show a curve more nearly approaching one hyperbolic formula. The failure of gas wells to be hyperbolic in most cases is probably the result of restriction of output, interference, etc. In actual practice the gas well curve approaches much more nearly a straight line on quadrille paper than the oil well, throughout most of its life. There is relatively a greater change of rate at a later history, followed in turn by a long period of slow decline, which seems quite inconsistent with its former more rapid decline. Much of this is, of course, merely mechanical, because there is a lesser difference between the well pressure and the line pressure during this period. However, it is true that this is not the sole factor, but

that many wells are capable of producing gas at two different rates, a large amount of gas quickly available from the gas sand proper, and another quantity available from peripheral zones of

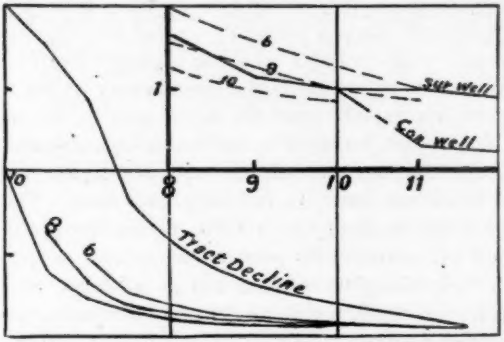


Fig. 10.—Analysis of a Tract Decline Curve.

sand where the pores are very much finer, so that the obstruction to flow is greater than in the sand body. A still slighter amount of gas is contributed from the slightly porous sandstone or sandy shale or minutely fissured shale which encloses the quick yielding reservoir. In other words a reservoir consists of concentric zones of increasing resistance to flow.

We have so far considered the individual well curve. Yet more than 95 per cent of the curves studied are tract curves. The tract curve varies necessarily from the individual well curves. In its early history it is made irregular by the bringing in of successive wells. Compared with a well curve this curve fails to show as rapid a decline. Moreover if we divide by the number of wells, as their number changes, we find that the average curve also shows too high a persistence. In other words it is too flat as compared with the decline curve of the wells individually. However, as soon as the last well is drilled in the tract the decline curve or the average of the wells shows a steeper rate than the individual curve would at the corresponding age, owing to the fact that the curve is now made up of some recent wells which are of course declining more rapidly than others which are producing from the beginning. However, as compared with individual well curves which start at the average time of com-

pletion the tract curve after the completion of the last well is less steep, since later new wells start off with a less steep rate than early new wells do.

It follows then that tract curves cannot give the same result as individual wells, and should not be expected to do so. Again the tract curve shows a step-like decline toward the end as the progressive abandonment of the wells takes place. Neither method of reducing the tract to an average can give the equivalent of the individual curve. Tract production curves should decline as such. They are very valuable because in the oil business we are handling tract units. We must not expect them to follow the individual curve. In depletion studies especially it should be remembered that we are studying the depletion of a tract, not well depletion.

There remains to discuss the now famous law proposed by Lewis and Beal, which has been called the law of equal expectations. This law has received three statements by the authors, "wells of equal output on the average will produce equal amounts of oil in the future regardless of the ages of the wells;" "if nothing of their character is know the futures of wells of equal output are by the law of chances equal." "On the average wells of equal yield will have approximately the same future productions regardless of the ages of the wells."

No one can dispute the fact that prior to the enunciation of this rule the rule of the age of the well compared with its size in our estimates of future production was over-estimated, so that the promulgation of this law has been of real value. Is not the law, however, improperly stated? To illustrate: The weight of a piece of type is determined by the amount of the lead, tin and antimony which were mixed in its manufacture. There were three different factors. If we say all pieces of type having equal amounts of lead will on the average weigh the same, the statement is correct, but it fails to tell us how much of the weight of the bar is produced by the weight of the lead and how much by other ingredients. It is then the amount of the influence we want to know, not that the size of the well has an influence. That we have always known. What Lewis and Beal have shown us is that the influence of the size of the well was much greater than we supposed. Yet as it is only one of several

factors, what we now need is a quantification of each of the factors. Will not our knowledge of the subject be better stated thus: "Many factors control the future production of oil wells, but its size at the time of reference is the leading factor?" Other important factors determining the amount of production from the time of reference are the age, the rate of decline, thickness of sand, viscosity, proportion of the pay which is oil filled, amount of dissolved gas, etc. Our future progress lies in measuring each of these circumstances under the various conditions. While for practical purposes it is very helpful sometimes to limit ourselves to one factor, such as size of the well, in the interest of accuracy or other figures, we must not delude ourselves by ignoring the other factors. Since it is feasible, as I have shown, to show age also on the same diagram, it is wiser to be influenced by the two variables than only one.

DISCUSSION

Mr. Johnson: I would like to ask Mr. Beal what rate of interest and what interval of compounding he would recommend in working out the compounding factor?

Mr. Beal: The rate of interest demanded would depend upon the risk involved. I think that it would be unwise to recommend any one rate for universal adoption. The interval of compounding, I think, should be a year. That's the one ordinarily used in compound interest. You may make it shorter or longer periods if you like, it makes no difference.

Mr. Johnson: Where the risk is not particularly great such as one of the large standard companies, and where the financial arrangements throughout the country may be concerned, what would you think would be a proper rate?

Mr. Beal: I should say that no company should expect less than eight per cent, and that twelve per cent is not unreasonable by any means in oil property investments.

Mr. Pepperberg: I think the papers this morning have been of vital interest to all of us and more especially to those of us who are interested in the [illegible] fields.

We are all interested in valuation at the present time, and these papers so ably presented bring us back more or less to the problems we will have to meet which concern Dr. Arnold's bureau. I have in mind some small tracts in the Texas field which are very irregular in shape. If we tried to value these tracts along the lines laid down by Mr. Beal, we would find we cannot map out a drilling campaign which will protect the property until we know what our neighbor intends to do. Unless an agreement is made with the owners of adjacent property, the cost of production and development will be much larger than naturally would be the case if we could develop along the lines which we think would be most economical.

Further, the consideration of the valuation of prospective, tentatively prospective or wildcat acreage is going to work a hardship on everyone, not only on those who own the property, but on those who appreciate that the exchange value of today,

as pointed out by Dr. Arnold, will not be the exchange value of tomorrow. Dr. Arnold suggests your lease might cost $1 per acre, that it may be close to a lease owned by one of the large oil producing companies, that this company may start the drilling of a well on their tract and that this nearby development will enhance the value of your lease in one day. These statements are true, but should the property be valued for taxation on the basis of its exchange value the day the large company begins drilling? It is possible that the well drilling near this lease is beyond the depth at which the oil is usually found in the district, in which case the price which you could get for it on the market would be less than you could have sold for before this depth was reached, especially if the well showed water where oil was expected. What is the value of the lease? This question must be answered by some of us when helping value the properties of our clients for taxation purposes. Should speculative value be considered, and if so, which should be given the most weight, the increased value due to close development or the chance that the property may never produce a drop of oil? Under present boom conditions, and considering the absence of known factors such as decline curves based on long terms of production by wells drilled close together, I see no proper way of valuing undeveloped acreage for taxation except on the amount paid for the acreage plus the rentals paid by the owner of the lease. I have in mind some tracts bought in this region a year ago at from $1 to $7.50 per acre. One of these tracts exchanged hands the other day for $315 per acre. This tract is two and one-half miles from production, and this notwithstanding the fact that tracts situated a quarter of a mile from production, and in some cases just across the fence, have proven unproductive.

Mr. Shaw: What Mr. Pepperberg says is indeed true. Speculation in leases is often gambling on psychological factors —on such matters as future individual enthusiasm and collective emotions akin to mob spirit. Hasty and wild guesses as to the oil values of tracts of land, particularly during an oil boom, may play havoc with a conservative business policy. The prices at which leases change hands are, however, market values, even if they are, to a good valuation engineer, ridiculous.

My paper deals with factors that I think should be considered in determining as closely as possible the earning power of

a property, and not its exciting power nor the excitement generated by either falsely reported or true discoveries on other properties. The doctrine of chance enters even this problem at many places. Consciously or unconsciously the chances of success and failure are more or less carefully or carelessly evaluated in every lease transfer. The probabilities also as to degree of success and failure of the venture as a whole and of each component part are sized up by hunches, instinct, or more or less inadequate computations.

Should the valuation engineer change his estimate because he thinks the market value will soon change abruptly without good reason, or because he thinks the price of oil is going to soar or decline in the near future? I think that there may be circumstances under which such action would be warranted, but as a rule the chances of being correct in prophesy of future rise in value are so small that they should be ignored by the buyer, though he may well trim his bid a little on account of his belief in a coming slump.

Mr. Washburne: I am very glad to see Mr. Beal is not afraid to estimate the future prices of oil. I think there are a great many appraisers who make estimates that turn out to be considerably under the value of the property, because they do not realize how much the price of oil has advanced. I made two appraisals some time ago in which I gave two different values to the property, one of which was based on the price of oil at that time, and one of which was based on my judgment of what the price of oil would probably be in the next three or four years. I also gave a third figure, derived from my personal opinion of the relative magnitude and importance of the various factors of the appraisal. This gave a valuation between the two extremes, and was the valuation recommended. The higher value has since turned out to be more nearly the correct one for most of that group of properties, because of the advance in the price of oil.

From this experience, and for other reasons, I believe we will find that the appraisals we are making today on the basis of our own opinion as to the future price of oil, will come closer to being the true value of that property, than any valuation based on the present price of oil.

In the various fields we can roughly estimate the factors that affect the future price of oil. If we are dealing with a field producing fuel oil in the Gulf Coast, we have to contend with the increase of competition of Mexico and Venezuela, and we cannot safely predict an advance in price for several years. If we are dealing with fields in the Pennsylvanian and Mid-Continent regions, we can predict an advance in price. These are high-grade refining oils, for which there is an increasing demand much in excess of production. If the Ranger region comes up to the maximum expectations, it might indicate that stocks will increase, but only for a short period, if at all. It is important to remember that most of the Ranger field is in large blocks, under the control of a few conservative producers, and that the income tax is high.

I do not expect such a flood of oil from the North Central Texas fields as would be required to greatly increase present stocks of refining oil in the United States. In other words, I do not expect more than a minor temporary cut in the price of crude oil, if indeed there will be any cut. North Texas is the only great field in sight in the whole United States. Therefore, I think the conclusion is quite safe that we may expect a general increase in the price of high-grade refining oil extending indefinitely in the future. Local problems, like at Ranger, where there might be temporary production in excess of transportation and storage capacity, may cause a temporary decline in that region, but as I look at it, we can pretty safely overlook these temporary features. In fact, it looks as though all Ranger oil will be handled quite easily.

I know that the most conservative engineers who are valuing copper and iron mines in the United States nearly all refuse to pay much attention to probable future changes in the price of copper and iron, but the future changes in the prices of those metals are not likely to be as important as are the changes in the price of oil.

I think perhaps that those who have approached appraisals through scientific methods and geology are inclined to be a little too scientific. There is nobody that has a higher appreciation than I have of the common-sense of the old-time oil operators, and of the men who have been actually buying properties for many years for some of the larger companies. It has been a matter

of much surprise to me to find how closely men have valued properties who know nothing of the scientific aspects of the problem. I have seen a great number of cases in which men, whose education consisted almost wholly of a long period of drilling wells, pumping them, etc., have estimated the value of a property closer than estimates made by high-salaried engineers, and it has made me realize the desirability of getting close to the ground in my own work. The study of individual wells day by day, gauging them, watching the water, how the water is increasing and decreasing, watching the freak wells on every property, because nearly every property has important freak wells, and things of that sort, will improve our calculated appraisals. These modifying conditions often are more important than all our scientific curves. I know of a number of cases already in my limited experience in which the production of a property determined by the decline curve methods was forty per cent off of what the actual production was.

Chairman: Too small or too great?

Mr. Washburne: Both ways, but usually the scientific method gave too large an estimated future production. Often the appraiser did not allow enough margin for the danger of water coming in from upper sand, or for the power breaking down more than expected, and for the wells being off the pump longer than expected, or for the sands gumming up with paraffin, etc. Many things may happen to decrease the actual production below what was figured by the decline curve method. I believe in every appraisal. If we can get good old experienced field men to go with us and study the wells and talk with us every day we are on the property, we will avoid some of these mistakes.

Mr. Johnson: Mr. Chairman, there is one thing I would like to speak of. An oil company consists of something more than an aggregate of tracts. It has a going concern value, and this seems to me to be of very great importance. I have bought stock in oil companies holding a valuable property where the going concern value was negative, as demonstrated by the quality of the new purchases which were made so ill-advisedly that the value of the shares of the company quickly fell. On the contrary, there are companies who have such efficient organizations that they are making regularly values not represented in

the actual tracts owned. Now the public utility appraisers call that a going concern value, and it seems to me to be very important.

Chairman: How are you going to appraise it?

Mr. Johnson: It is very difficult, far more so than the tangibles, but it can't be ignored if you wish to advise an investor about the value of those tracts. A strong company has a valuable asset in its extensive avenues of knowledge through its scouts and geologists, and another in the fact that valuable offers are regularly coming to it frequently at first hand. I am inclined to think that the greatest errors in company appraisals lie in the general ignorance of this going concern value, although I admit with you, Mr. Chairman, that it is extremely difficult to estimate.

Mr. Bates: I agree with Mr. Johnson in a great many ways on the Osage. I have recently done a good deal of work in that territory, but I would suggest that I believe his plan would fall down unless he shows the shore line along the streams, along the strikes. I agree very much with Mr. McCoy in his theory of shore lines. If you take production in the Osage, you will find it is a series of shore lines, and the larger wells are along the points where you get little flexures that give the looser sand, and if you have these structures along that sand you will get greater production, and that doesn't follow at any particular place. West of Range 8 you don't get any Bartlesville sand. You don't get any of the Canyon east of Range 8.

Mr. Heald: I should like to ask Mr. Johnson if the basins which he considered are the larger basins, the nonsynclines, or whether some of them are really integral parts of the closure.

Mr. Johnson: Each one was taken strictly on closeure, and therefore some would have relationship with other parts which would affect them.

Mr. Hagar: I would like to ask Mr. Johnson what percentage of production was due to lensing in the Osage.

Mr. Johnson: I think that it is premature at this time, owing to the fact that we are testing the domes first, as we ought to do. We never will know how much oil is controlled by lensing conditions there, because the unrelated homoclines are

never as well related as the anticlines. We go after those anticlines first, as we should. We are going to check up these other things later, and we will continue to check them up for years and years, just as we have in the Appalachian field. In fact, we are getting pools now which are lensing and will be controlled by that situation, and I think that the Osage will simply repeat history in that respect.

CORRESPONDENCE

Tulsa, Okla., March 3rd, 1919.
611 South Boulder.

Mr. W. E. Wrather,
Sec'y American Ass'n. Pet. Geologists,
Dallas, Texas.

Dear Sir:-

In the Bulletin (1918) of the Association, which has just come to hand, I note paper by Dr. D. W. Ohern entitled "A Contribution to the Stratigraphy of the Red Beds."

It may seem out of place to criticize a valuable scientific paper upon grounds other than technical, but it seems to the writer that all matters of history in such papers should be kept straight.

I refer to the statement as follows: "As late as 1912 it was considered that the eastern limit of the Red Beds was the western dead line for oil and gas." This statement should be limited. It may be that Dr. Ohern then considered it the dead line, and memory is that other Geologists so considered it. At any rate the writer found it very difficult to obtain scientific or practical aid in the Southern Oklahoma country when he was doing his best to discover oil there in 1904. The struggle was singlehanded and against odds, and the encouragement and assistance of Geologists and practical oil men would have been appreciated.

Attention is called to Bulletin of the Oklahoma Geological Survey by L. L. Hutchison published in 1910, in which the

oil and gas operations of the Santa Fe (of which the writer was manager) at Wheeler, Carter County, were described. While in those days market for the small production of oil coming from the Wheeler wells was lacking, reference is made to the fact that gas was turned into an eighteen mile 6 1-4 inch line from Wheeler to Ardmore on December 12th, 1907. I think the records will show that Ardmore had natural gas one week before Oklahoma City. From that time until that which Dr. Ohern mentions as the beginning of attention to the Red Beds country (five years) the city of Ardmore used natural gas from wells in the Red Beds country.

Sometimes, pe-haps generally, all the pioneer has as results of his efforts, are experiences. These have only a personal interest, and are not particularly interesting to others, but as regards the history of Southern Oklahoma oil it appears that the Red Beds problem, only when it once showed commercial value at Healdton, waked up both practical man and scientist.

Yours very truly,

H. B. Goodrich.

My Dear Mr. Deussen:

In my discussion of the Cement Field, Oklahoma, on page 56 Bulletin of the American Association of Petroleum Geologists, Vol. 2, Mr. Frank Buttram, Geologist, Fortuna Oil Company is quoted as follows: "It is the opinion of Mr. Buttram, that this well (Fortuna Oil Company's well in the Southwest corner of Sec. 31, T. 6 N, R. 9 W) started in the Pennsylvanian, and that all the production in this well is from the Pennsylvanian strata." The word "Pennsylvanian" should be changed to read "Permian."

In this connection, Mr. Buttram wishes to make the following statements, and I will appreciate your reading them at the meting of the Association at Dallas:

1. The Whitehorse sandstone, which outcrops at Cement, has a maximum thickness of not less than 250 feet, part of which is below the surface as shown by well logs. Since the Whitehorse sandstone is Permian, it follows that the wells in the Cement Field start in the Permian.

2. Below the 2367 foot oil sand horizon of the Gingrich No. 1, in the southeast corner of NW 1-4 of the NW 1-4 of Sec. 6, Twp. 5 N, R. 9 W, the formations are typically Pennsylvanian.

3. According to present data it could be said in a general way that the probable contact between the Permian and Pennsylvanian in the Cement Field is at a depth of about 1700 feet. However, the gradation from the Permian to the Pennsylvanian is very gradual and there is no distinct horizon separating the two. It may be that chemical analyses of water and material from wells drilled in the future in this field would give more definite data from which the exact horizon between the Permian and Pennsylvanian could be determined.

4. It should be kept in mind that the base of the red material reported in well logs does not necessarily coincide with the base of the Permian because well logs in the Cushing Field show a number of red shale strata to a depth of about 1000 feet and the wells in this field are known to start in the Pennsylvanian.

5. The present development in the Cement Field indicates that the underground structure conforms fairly closely with the surface structure, which suggests that there is no marked unconformity between the Permian and Pennsylvanian strata.

Very truly yours,
GEORGE E. BURTON.